Converting Commercial Vehicles to locally emission-free Drive Technologies

Potentials and Framework Conditions

CONVERTING COMMERCIAL VEHICLES TO LOCALLY EMISSION-FREE DRIVE TECHNOLOGIES

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Ing. Holger Heinfellner, BSc
DI Norbert Sedlacek
Anne Glatt, MSc
Johanna Bürger, MSc
Johanna Vogel, DPhil

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Project Manager Ing. Holger Heinfellner, BSc

Authors DI Norbert Sedlacek (Herry Consult)
Ing. Holger Heinfellner, BSc
Anne Glatt, MSc
Johanna Bürger, MSc
Johanna Vogel, DPhil

Layout Thomas Lössl

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ABSTRACT

Ongoing climate change and its increasingly visible consequences are among the greatest challenges of the 21st century. The transport sector is one of the main emitters of greenhouse gases (GHG), and data from recent years show an increasing trend in GHG emissions from transport. This contrasts with ambitious targets such as climate neutrality by 2040 at the latest in accordance with Austria's Government Programme 2020-2024. In order to reach this target, Austria's 2030 Mobility Master Plan sets target years from which only zero-emission vehicles are to be newly registered. There are only 5–10 years between these target years and the target year for climate neutrality.

However, the average life span of vehicles of different categories suggests that there will still be a significant quantity of conventionally powered vehicles in the Austrian vehicle fleet in 2040. This can be addressed in several ways:

1. push and/or pull measures for an early withdrawal of internal combustion engines from the vehicle fleet (environmental zones, driving bans, costs for fossil fuels, etc.).
2. operation of the remaining fleet powered by internal combustion engines with climate-neutral liquid fuels (e.g. 100 % biodiesel, electricity-based synthetic fuels)
3. **conversion of existing used vehicles from internal combustion engine to electric drive**

With regard to the third point, the present ***ConVErT*** study examines the potentials, opportunities and framework conditions for the conversion of commercially used vehicles in Austria.ConVErT performed a holistic assessment of the topic of retrofitting vehicles of categories N1, N2, N3, semi-trailers and M2/M3 and its implications for Austria as a business location. To this end, a comprehensive market analysis of current and future retrofit solutions and the companies behind them was carried out. In parallel, the legal framework at national and European level which directly or indirectly affects the retrofitting of vehicles was identified. By interviewing relevant stakeholders and researching the literature, obstacles for the efficient and economical conversion of a large number of vehicles were identified and corresponding proposals for improvement were developed.

As the next step, the Excel-based fleet model of the Environment Agency Austria (*Umweltbundesamt*) was used to estimate how many vehicles per vehicle category included in the study could be subject to vehicle conversion. Using the corresponding emission factors from the Handbook Emission Factors (HBEFA) and previous work relevant to the topic, we estimated how the retrofits would affect the direct and indirect GHG emissions.

Furthermore, based on information from different retrofit providers as well as research of the literature, the current and future retrofit costs were estimated per vehicle category. The total cost of ownership (TCO) model developed by Herry Consult was applied to compare the TCO of converted vehicles with the

TCO of newly purchased fully electric vehicles. From the TCO analysis, a potential need for governmental retrofit premiums was identified and quantified.

Based on the estimated component costs as well as the potential number of vehicles to be converted, the economic potential from the production and assembly of conversion solutions by Austrian companies was quantified using the macroeconomic input-output model MIO-ES. Further, all the insights gained were applied in qualitative work to those vehicle categories that were not the focus of the study.

Based on the work carried out, a total of eleven recommendations for action were identified and formulated in three overarching focus areas:

Creating an appropriate legal framework

1. Creation of a uniform, harmonised legal framework in the European Union regarding the homologation process for converted vehicles: This should be done in consultation with policymakers, the administration and industry. The homologation process should be simplified and accelerated. At the same time, high quality and safety standards must be ensured. When designing the legal framework, all vehicle categories should be included, especially commercial vehicles. The aim is to establish a European retrofit market that enables a significant number of vehicle series to be retrofitted quickly and economically.
2. Accreditation of certified workshops throughout the EU and for all of the EU: This means that there should be no confinement of workshops to a national territory (as is the case in France). In France, the retrofit can only be carried out by installers in the territory of France, which works against the establishment of an EU-wide retrofit market. Instead, certified workshops should be allowed throughout the territory of the EU.
3. Standardised build-up of knowledge in the various technical services with regard to retrofit as well as testing and approval procedures: For this purpose, the "Forum for Exchange of Information", which was introduced with Regulation (EU) 2018/858, could be used to exchange information between the EU countries and their technical services regarding retrofitting. It is recommended that the necessary competences and resources in the relevant (technical) institutions in Austria are built up.
4. Vehicle approval with regard to the maintenance of the permitted payload despite the increase in the tare weight through the vehicle conversion (because of the battery weight) should be examined under national law. (This is already partly implemented in Article 10b of Directive 96/53/EC.)

Setting economic incentives

5. National funding framework for retrofitting vehicles: This should reduce retrofit costs and stimulate the retrofit market in order to realise the potential retrofit volumes from 2030/2035. This support for retrofitting is recommended until 2030/2035. The continuation of this funding beyond this date should be examined in a timely manner. This will depend on the

remaining conventional vehicle volumes and the maturity of the retrofit market by then.

6. The subsidy amount should be adjusted individually according to the vehicle class and should be in proportion to the subsidy for a new BEV purchase. An ongoing evaluation of the quantities and the TCO, comparing a new BEV purchase with a retrofit, is necessary in order to continuously adapt the subsidies to the situation and to do so at the appropriate time.
7. The funding regime should be designed such that it is only the end customer and not the retrofitter who is funded in order to ensure that this stimulates the retrofitting of the Austrian vehicle fleet. It should also be ensured that the vehicle for which the subsidy is granted is registered in Austria.
8. The type-approval of converted vehicles should not entail high costs because costs that are too high for the certification would prevent the economical conversion of significant quantities of vehicles. Therefore, a further economic incentive should be provided by reducing costs for the official type-approval of the converted vehicle.

Strengthening Austria as a business location

9. The retrofit market in Austria needs a push to be established. Therefore, a national task force on retrofitting is recommended in order to encourage networking between the retrofit industry players in Austria and to develop a criteria catalogue for retrofitting (along the lines of the one for Germany).
10. Training offensives for the workforce in all sectors relevant to the retrofit market should be created. This is particularly important in the areas of maintenance and repair of motor vehicles (which can become certified retrofitting companies for commercial vehicles), manufacture of electrical equipment (for the production of electric motors, batteries and charging systems) as well as manufacture of machinery and equipment (for the production of other conversion kit components such as heating/cooling units). Retraining workers in the motor vehicles repair sector as retrofitters may help halt possible job losses in that area with the rise of less maintenance-intensive battery electric vehicles.
11. In addition, the establishment of production facilities in Austria for the necessary conversion components should be supported in order to fully utilise or even increase the economic potential (e.g. production facilities for batteries). Subsidies for the conversion of production from combustion engine to electric drives can also be considered for this purpose.

ZUSAMMENFASSUNG

Der fortschreitende Klimawandel und seine zunehmend sichtbaren Folgen gehören zu den größten Herausforderungen des 21. Jahrhunderts. Der Verkehrssektor ist einer der Haupttreibhausgasemittenten und die Daten der präpandemischen Jahre bis 2019 zeigten einen steigenden Trend bei den verkehrsbedingten Treibhausgasemissionen. Dem gegenüber stehen ambitionierte Ziele, wie jenes der Klimaneutralität bis spätestens 2040 gemäß dem österreichischen Regierungsprogramm 2020-2024. Um dieses Ziel zu erreichen, legt der *Mobilitätsmasterplan 2030 für Österreich* Zieljahre fest, ab denen nur noch emissionsfreie Fahrzeuge neu zugelassen werden sollen. Zwischen diesen Jahren und dem Zieljahr für Klimaneutralität liegen nur fünf bis zehn Jahre.

Die durchschnittliche Lebensdauer von Fahrzeugen verschiedener Kategorien liegt teilweise deutlich über diesen fünf bis zehn Jahren. Das lässt darauf schließen, dass im Jahr 2040 immer noch eine beträchtliche Anzahl an konventionell angetriebenen Fahrzeugen in der österreichischen Fahrzeugflotte sein könnte. Diesem Umstand kann auf mehrere Arten begegnet werden:

1. Push- und/oder Pull-Maßnahmen für einen vorzeitigen Ausfall von Verbrennern aus der Fahrzeugflotte (Umweltzonen, Fahrverbote, Kosten für fossile Kraftstoffe etc.)
2. Betrieb der verbrennungsmotorisch betriebenen Restflotte mit klimaneutralen flüssigen Kraftstoffen (z. B. 100 % Biodiesel, strombasierte synthetische Kraftstoffe)
3. **Umrüstung bestehender Gebrauchtfahrzeuge von Verbrennungsmotor auf Elektroantrieb**

Im Zusammenhang mit dem dritten Punkt der Fahrzeugumrüstung untersucht die gegenständliche Studie die Potenziale, Chancen und Rahmenbedingungen für die Umrüstung von gewerblich genutzten Fahrzeugen in Österreich.

ConVErT beleuchtet das Thema der Umrüstung von Fahrzeugen der Kategorien N1 (Lkw ≤ 3,5 t hzG), N2 (Lkw > 3,5 t hzG und ≤ 12 t hzG), N3 (Lkw ≥ 12 t hzG), Sattelzüge sowie M2/M3 (Omnibusse) und die Implikationen für den österreichischen Wirtschaftsstandort. Dazu wurde zunächst eine umfassende Marktanalyse zu derzeitigen und zukünftigen Umrüstlösungen und den dahinterstehenden Unternehmen durchgeführt. Parallel dazu wurden die rechtlichen Rahmenbedingungen auf nationaler und europäischer Ebene identifiziert, die sich direkt oder indirekt auf die Umrüstung von Fahrzeugen auswirken. Durch die Befragung relevanter Akteure und mithilfe von Literaturrecherchen wurden Hindernisse für die effiziente und wirtschaftliche Umrüstung einer großen Zahl an Fahrzeugen identifiziert und entsprechende Verbesserungsvorschläge ausgearbeitet.

Im nächsten Schritt wurde unter Einsatz des Flottenmodells des Umweltbundesamtes abgeschätzt, wie viele Fahrzeuge je Fahrzeugkategorie im Fokus der Arbeit grundsätzlich von einer Fahrzeugumrüstung betroffen sein

könnten. Mit entsprechenden Emissionsfaktoren aus dem Handbuch für Emissionsfaktoren (HBEFA) bzw. Aus themenrelevanten Vorarbeiten wurde abgeschätzt, wie sich die Umrüstungen auf die direkten und indirekten Treibhausgasemissionen auswirken würden.

Des Weiteren wurden auf der Grundlage von Informationen verschiedener Umrüstungsanbieter sowie von Literaturrecherchen die derzeitigen und zukünftigen Umrüstkosten je Fahrzeugkategorie abgeschätzt. Unter Anwendung eines TCO-Modells wurden die „Total Costs of Ownership“ (TCO) der umgerüsteten Fahrzeuge mit den TCO vollelektrischer Neufahrzeuge verglichen. Anhand der TCO-Analyse wurde ein potenzielles Erfordernis an staatlichen Umrüstprämien identifiziert und berechnet.

Basierend auf den geschätzten Komponentenkosten sowie der potentiellen Anzahl umzurüstender Fahrzeuge wurde das volkswirtschaftliche Potential durch die Produktion von Umrüstlösungen in Werkstätten in Österreich unter Einsatz des makroökonomischen Input-Output-Modells MIO-ES quantifiziert. Darüber hinaus wurden alle gewonnenen Erkenntnisse in qualitativer Weise auf jene Fahrzeugkategorien umgelegt, die nicht im Fokus der Studie stehen.

Aufbauend auf den durchgeführten Arbeiten wurden in Summe elf Handlungsempfehlungen in drei übergeordneten Fokusfeldern identifiziert und formuliert:

Geeigneten Rechtsrahmen schaffen

1. Schaffung eines einheitlichen, harmonisierten Rechtsrahmens in der Europäischen Union für das Homologationsverfahren für umgebaute Fahrzeuge: Dies soll in Abstimmung mit Politik, Verwaltung und Industrie geschehen. Das Homologationsverfahren soll vereinfacht und beschleunigt werden. Gleichzeitig müssen hohe Qualitäts- und Sicherheitsstandards gewährleistet werden. Bei der Ausgestaltung des Rechtsrahmens sollen alle Fahrzeugklassen, insbesondere Nutzfahrzeuge, einbezogen werden. Ziel ist es, einen europäischen Nachrüstungsmarkt zu etablieren, der die schnelle und kostengünstige Nachrüstung einer nennenswerten Anzahl von Fahrzeugserien ermöglicht.
2. Akkreditierung von zertifizierten Werkstätten im und für den gesamten EU-Raum: Das bedeutet, dass es keine Beschränkung der Werkstätten auf ein nationales Territorium (wie in Frankreich) geben sollte. Stattdessen sollten zertifizierte Werkstätten im gesamten EU-Gebiet zugelassen werden.
3. Standardisierter Wissensaufbau in den verschiedenen technischen Diensten in Bezug auf Nachrüstung sowie Prüf- und Zulassungsverfahren: Dazu kann das, mit der Verordnung (EU) 2018/858 eingeführte „Forum für Informationsaustausch“ genutzt werden, um Informationen zwischen den EU-Ländern und ihren technischen Diensten zum Thema Nachrüstung auszutauschen. Es wird empfohlen, die notwendigen Kompetenzen und Ressourcen in den relevanten (technischen) Institutionen in Österreich aufzubauen.

4. Die Fahrzeugzulassung im Hinblick auf die Einhaltung der zulässigen Nutzlast trotz der Erhöhung des Eigengewichts durch den Fahrzeugumbau (wegen des Batteriegewichts) ist nach nationalem Recht zu prüfen.

Ökonomische Anreize setzen

5. Nationaler Förderrahmen für die Nachrüstung von Fahrzeugen: Dadurch sollen die Nachrüstkosten gesenkt und der Nachrüstmarkt stimuliert werden, um das potentielle Nachrüstvolumen ab 2030/2035 realisieren zu können. Diese Förderung der Nachrüstung wird bis 2030/2035 empfohlen. Eine Fortführung dieser Förderung darüber hinaus sollte rechtzeitig geprüft werden und ist unter anderem abhängig von der Anzahl der verbleibenden konventionellen Fahrzeuge, sowie der Reife des Nachrüstungsmarktes zu diesem Zeitpunkt.
6. Die Förderhöhe ist je nach Fahrzeugklasse individuell anzupassen und sollte in einem angemessenen Verhältnis zum Zuschuss für einen BEV-Neukauf stehen. Eine laufende Evaluierung der Stückzahlen und der TCO im Vergleich von BEV-Neukauf und Nachrüstung ist notwendig, um die Förderung kontinuierlich an die Situation anzupassen und zu gegebener Zeit nachzusteuern.
7. Das Fördersystem wird so gestaltet, dass der Endkunde und nicht der Nachrüster gefördert wird, um sicherzustellen, dass dadurch die Nachrüstung des österreichischen Fuhrparks angeregt wird. Desweiteren wird sichergestellt, dass das geförderte Fahrzeug in Österreich zugelassen wird.
8. Die Typgenehmigung von umgerüsteten Fahrzeugen sollte keine hohen Kosten verursachen, denn zu hohe Kosten für die Zulassung würden die wirtschaftliche Umrüstung von Fahrzeugen in nennenswerten Stückzahlen verhindern. Ein weiterer wirtschaftlicher Anreiz soll daher durch reduzierte Kosten für die behördliche Typgenehmigung des umgerüsteten Fahrzeugs geschaffen werden.

Wirtschaftsstandort stärken

9. Der Nachrüstungsmarkt in Österreich braucht einen Schub, um sich zu etablieren. Daher wird eine nationale Task Force Nachrüstung empfohlen, um die Akteur:innen der Nachrüstungsbranche in Österreich zu vernetzen und einen Kriterienkatalog für die Nachrüstung (nach dem Vorbild Deutschlands) zu entwickeln.
10. Es sollten Schulungsoffensiven für die Beschäftigten in allen für den Nachrüstungsmarkt relevanten Bereichen geschaffen werden. Besonders wichtig ist dies in den Bereichen Wartung und Reparatur von Kraftfahrzeugen (die zu zertifizierten Umrüstbetrieben für Nutzfahrzeuge werden können), Herstellung elektrischer Ausrüstungen (für die Produktion von Elektromotoren, Batterien und Ladesystemen) sowie Herstellung von Maschinen und Anlagen (für die Produktion anderer Umrüstungskomponenten wie z. B. Heiz-/Kühlgeräte). Die Umschulung

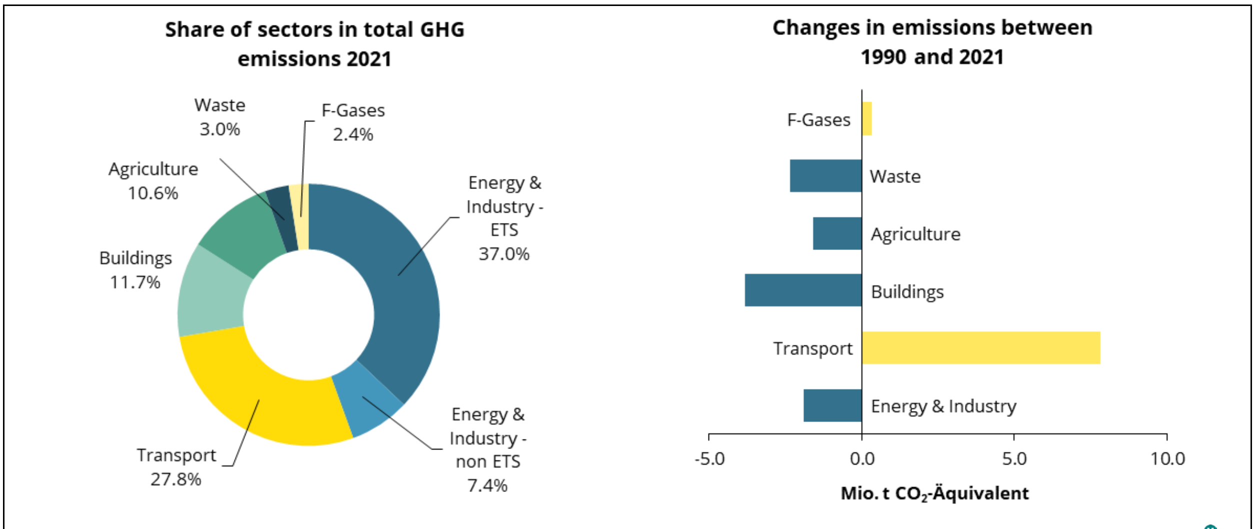
von Arbeitnehmer:innen in der Kfz-Reparaturbranche zu Umrüster:innen kann dazu beitragen, mögliche Arbeitsplatzverluste in diesem Bereich durch die Zunahme weniger wartungsintensiver batterieelektrischer Fahrzeuge aufzuhalten.

11. Darüber hinaus wird der Aufbau von Produktionsstätten in Österreich für die notwendigen Umrüstungskomponenten unterstützt, um das wirtschaftliche Potenzial voll auszuschöpfen bzw. Noch zu steigern (z. B. Produktionsstätten für Batterien). Zu diesem Zweck können auch Förderungen für die Umstellung der Produktion von Verbrennungsmotoren auf elektrische Antriebe in Betracht gezogen werden.

1 BACKGROUND AND INTRODUCTION

Ongoing climate change and its increasingly visible consequences are among the greatest challenges of the 21st century. The unexpected speed at which climate change is progressing underlines the need for a rapid and profound transformation of global social and economic systems (IPCC, 2021). The transport sector is one of the main emitters of greenhouse gases: According to the latest information, its share of total global greenhouse gas emissions is around 16 % (RITCHIE and ROSER, n.d.); in Austria, the transport sector's share is as high as 28 % (UMWELTBUNDESAMT, 2022-a), as illustrated in Figure 1.

Figure 1: GHG emissions in Austria in 2020



Source: Umweltbundesamt

On the other hand, there are ambitious targets that require a rapid and complete reversal of the trend in greenhouse gas emissions, and more or less comprehensive action plans have been published at various levels to pave the way for achieving these goals.

Paris Climate Agreement

The overarching goal of global climate policy is to meet the 2°C target. This is in line with the scientific findings of the Intergovernmental Panel on Climate Change (IPCC) and was reaffirmed by the Paris Climate Agreement of December 2015. This agreement aims at limiting global warming to well below two degrees Celsius compared to pre-industrial times, and if possible to 1.5 degrees Celsius. For industrialised countries, this means largely abandoning the use of fossil fuels by the middle of the century. The Member States of the European Union have signed this contract.

European Green Deal and "Fit for 55"

In addition, the European Green Deal was published at European level in December 2019 (COM(2019) 640 final) and, in July 2021, the European Commission presented the "Fit for 55" climate and energy package. This package comprises eight dossiers and five legislative proposals to revise and update the first relevant European Union legislation. One of these proposals calls for the specific CO_2 emissions of newly registered passenger cars and light commercial vehicles (LCV) to be 55 % and 50 % lower, respectively, in 2030 than in 2021, and for only zero-emission vehicles in these vehicle categories to be newly registered in 2035. In the heavy-duty vehicle (HDV) sector, the target is still for newly registered vehicles to emit 30 % less CO_2 in 2030 than in 2019.

Austria's 2030 Mobility Master Plan

At the national level, the Austrian federal government has adopted the Government Programme 2020-2024, which has a significantly higher level of ambition than the European targets (BKA, 2020). Cross-sectoral climate neutrality is to be achieved as early as 2040. Austria's 2030 Mobility Master Plan shows how this goal can and should be achieved in the transport sector (BMK, 2021). This plan was published in July 2021 and is based on the fundamental assumption that in 2040 only a certain amount of renewable energy (required for complete decarbonisation) will be available to the transport sector when viewed holistically. This master plan includes the following key objectives:

- 100 % of all new car and two-wheel registrations will be zero-emission by no later than 2030;
- 100 % of all new bus registrations will be zero-emission by 2032;
- 100 % of all new light commercial vehicle registrations will be zero-emission by no later than 2030;
- 100 % of all new heavy-duty vehicle registrations (vehicles over 18 tonnes) will be zero-emission by 2035.

All the above-mentioned vehicle categories generate different specific annual mileages, which generally decrease with the age of the vehicle. The useful life of a vehicle in Austria depends on numerous variables and averages 10 to 15 years (UMWELTBUNDESAMT, 2021-a), depending on the vehicle category.

Converting vehicles as additional measure to achieve climate neutrality

A comparison with the above-mentioned new registration targets for zero-emission vehicles thus shows that the time span between the new registration targets according to the Mobility Master Plan and the goal of climate neutrality according to the Government Programme is too short to ensure climate neutrality in 2040 through the new registration of zero-emission vehicles alone. Instead, additional measures are needed. Adopting technical measures, such as converting vehicles with internal combustion engines to locally emission-free drives, is one option to address these challenges, and this option is the core topic of the ConVErT project, which is explained in detail below.

2 PROJECT OVERVIEW

2.1 Project goals

Evaluation of the potential of retrofitting

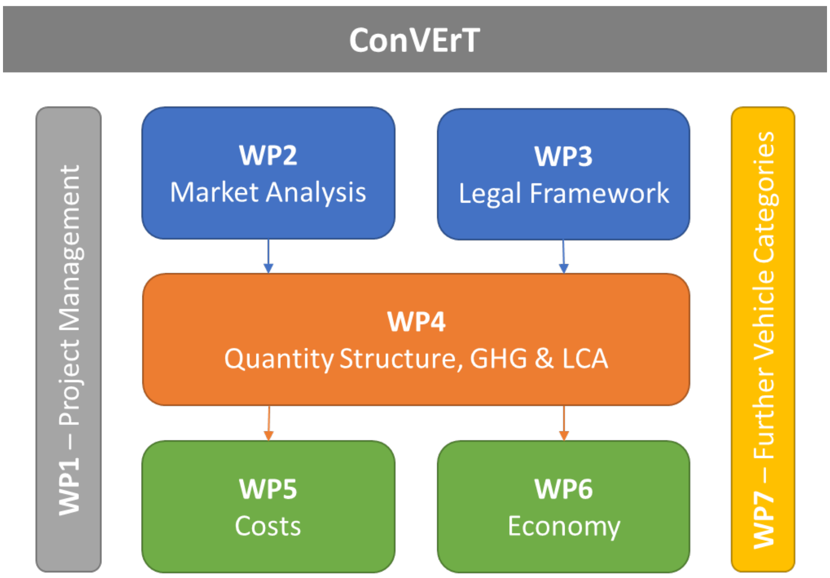
Statistical analyses show that even if only zero-emission vehicles are newly registered in 2030, there will still be a significant number of vehicles with internal combustion engines in 2040. The ConVErT study sought to quantify these vehicle volumes in the area of vehicles used commercially using the EAA fleet model and to identify those current and future technologies that are available for converting these vehicles to zero-emission drives. In parallel, the European legal framework was to be examined for weaknesses, and the current and future costs determined to enable the discussion of a possible state subsidy for conversion. For evaluating TCO, for calculating the potentials for the reduction of direct and indirect GHG emissions, and for appraising the economic potential from the production and assembly of conversion solutions by Austrian companies, models were used that had already been applied by the project partners for several years and are constantly being developed further.

2.2 Project structure and schedule

The project consisted of seven integrative work packages. The following figure shows the ConVErT project structure and the interaction between the work packages in terms of their content.

Figure 2: Project structure

Structure of the ConVErT project



Source: Umweltbundesamt and Herry Consult

3 MARKET ANALYSIS

This chapter provides an overview of the relevant technological aspects of the conversion of vehicles. This is followed by a summary of the advantages and disadvantages of different technologies. Finally, a desktop research-based analysis of existing suppliers and their conversion strategies is presented.

3.1 Overview of technologies

Common technologies used for conversion to locally emission-free vehicles were identified based on a broad analysis of the literature and online resources concentrating on Europe but also including studies and information from the USA, Japan and China (if provided in English or German). In addition to this desktop research, selected retrofit providers were contacted and asked to complete a questionnaire focusing on

- Market analysis: installed technologies, vehicle types, quantities so far, retrofit capacities, retrofit components, component lifetimes, changes in vehicle weight and mass distribution, warranty terms, collaborations (relevant to chapter 3);
- Legal framework: homologation process, differences between EU Member States, legal barriers, need for harmonisation, essential standards & regulations (relevant to chapter 4);
- Costs: retrofit cost, component costs, changes in costs (relevant to chapter 6).

For the detailed questionnaire, see Annex A – Questionnaire.

The research was broken down into the following different aspects:

- Existing versus expected future technologies;
- Basic technologies;
- Specific components of these basic technologies;
- Conversion methods;
- Organisational aspects.

In general, it must be noted that the findings in terms of core technologies do not differ between new zero-emission vehicles and converted vehicles. The same basic technologies are used and are expected to be used in future, and the same components are necessary for both cases.

Existing technologies

The basic conversion technologies for all types of vehicle are:

- Battery Electric Vehicles (BEV);
- Fuel Cell Electric Vehicles (FCEV) – powered by H_2 or methanol (not locally emission-free – not part of this study).

Other main basic technologies do not currently exist.

Future technologies

Besides these two main technologies, only the conversion to hybrid vehicles able to use future electric roads can be anticipated as a further basic technology (AEA et al., 2022). For such electric roads (hybrid solution with electricity supply from the road e.g. by a catenary system and BEV) practical tests are already being carried out but no commercial system exists yet (either for new vehicles or for converted vehicles).

Further basic technologies are not expected anywhere (the same situation as for new vehicles). In addition, scientific studies do not predict any further future basic solutions.

However, the development of existing technologies (e.g. battery technology) is expected.

Further analysis focuses therefore on BEV and FCEV.

Conversion components

Different components and steps are necessary to convert conventional vehicles to BEV or FCEV. The main components are the same for all types of vehicle. Specific components differ between buses and trucks or between types of axle (low-floor). The conversion to FCEV needs additional components compared to BEV.

Components for conversion to BEV (CLEAN LOGISTICS, n.d., WAHNSCHAFFE, 2018, ALTENBURG, 2014, feedback during interviews):

- Electronic controller, battery, charging system, power converter, electric motor;
- Transmission unit and drive axle in specific cases;
- Ancillary components (e.g. heating, cooling) powered with internal combustion engine (ICE) before conversion.

Components for conversion to FCEV (CLEAN LOGISTICS, n.d., ECAP, n.d., feedback during interviews):

- Electronic controller, battery, charging system, power converter, electric motor;
- Fuel cell stack, fuel filler, hydrogen tank;
- Transmission unit and drive axle in specific cases;
- Ancillary components (e.g. heating, cooling) powered with ICE before conversion.

Besides the components that are necessary to convert conventional vehicles to BEV or FCEV, it might be necessary to redesign parts of the vehicle. Possible reasons for a redesign:

- Space needed for integration of batteries (including the necessary consideration of weight distribution regarding axle and/or centre of gravity);
- Space needed for integration of the hydrogen tank (FCEV);
- Integration of a drive axle with e-motor (for low-floor buses).

Different technology options exist for the core components for conversions (battery and electric motor). This is the same situation as for the development and setup of new BEV or FCEV.

- Most common battery technologies for BEV/FCEV (analysis of retrofit company websites):
  - Lithium-ion (Li-ion) battery:
    - NMC (lithium nickel manganese cobalt oxide);
    - LFP (lithium iron phosphate);
    - Lithium polymer.
  - Future development:
    - SIB (sodium-ion battery);
    - Solid-state battery (partly already in use, Li-ion-based).
- Most common e-motor technologies for BEV/FCEV (analysis of retrofit company websites):
  - Permanent magnetic synchronous motor;
  - Separately excited synchronous motor;
  - Induction motor.

Conversion methods

The conversion of ICE to BEV or FCEV is done differently by the various retrofit providers. The methods used depend on the specialisation and capacities of the providers as well as organisational aspects (see the next section of this chapter) and the demand for conversion, which varies according to vehicle type but also vehicle make.

The different approaches for converting ICE to BEV or FCEV can be grouped into the following four methods:

Single vehicle-by-vehicle conversions: This method has been and still is used for initial solutions and for testing conversion technologies as well as for specific vehicle types with low quantities (e.g. classic cars, makes and models with a very low number of existing vehicles, off-road solutions). These single solutions are more labour-intensive than others (that use a kit-based method). Currently, more or less all solutions for conversion to FCEV are single conversion solutions. This is due to the fact that solutions are still being developed and demand is rather low.

Conversion kits to be used for specific vehicle categories and types: Conversion kits are developed and produced for selected makes and models of vehicle. They cannot be used for other vehicle makes or models. The kits therefore integrate almost all necessary conversion components, right down to the smallest parts (e.g. screws). This leads to a rather low number of conversions for each specific type of kit. Economies of scale cannot be exploited to optimal effect.

Conversion kits to be used for a large number of vehicle makes and models: Component integration must be reduced if conversion kits are to be used for different makes and models of vehicle, otherwise it is not possible to use them for different vehicles. This allows a higher number of kits to be produced, reducing the costs per kit. On the other hand, some small parts needed for conversion are not included in the kit and might increase the cost of conversion because they have to be produced separately.

Modular conversion kits: This method tries to combine the advantages of kits for specific vehicle types and those of general kits. This enables a high number of kits to be produced for a large variety of different makes and models of vehicle with the integration of as many components as possible that have to be converted. This method is the most advanced one and aims at high conversion quantities to reduce the price per conversion.

Organisational aspects

The organisation of the conversion when using conversion kits that enable a high number of conversions is another relevant aspect besides the different conversion methods. This mainly revolves around whether or not the production of the kit and the conversion itself are carried out by the same company. The following organisational possibilities in relation to the kit production and conversion work currently exist:

All under one roof: Companies that offer the conversion technologies and the conversion itself. This solution reduces the interfaces. The disadvantage is that the conversion capacity could be limited. The capacity bottleneck is not in the production of the kits, but in the conversion itself. If a company does both, large capacities at several conversion sites have to be built up and made available.

Development and production of conversion kits: Companies focusing on the creation of conversion kits and collaborating with companies that perform the conversion. Specialising in the development and production of the conversion kits enables these companies to reduce prices for the kits and to increase the number of kits produced. The partner companies that use the kits to perform the conversions may be existing car workshops with specific certificates. Collaborating with a number of car workshops enables an increase in the overall conversion capacities and a better spatial distribution of these capacities.

Execution of conversion: Companies using conversion kits developed and produced by other companies.

To enable the development and production of conversion kits to be separated from the conversion work itself, a training and certification system must be developed that involves the companies producing the conversion technologies and the companies executing the conversion. This is extremely important to ensure quality, safety and a customer warranty. At the moment, the collaboration between kit producers and converting companies is mostly regulated by the kit producers. A legal framework does not really exist yet (see chapter 4).

Technology by vehicle category

Commercial vehicles (N1, N2, N3, M2, M3) are the main focus of the ConVErT project. The different (technology) options described in this chapter (basic technologies, conversion components, conversion methods and organisation of conversion) are relevant to all categories of commercial vehicle. A specific selection of specific technologies for specific categories serves no purpose. However, different options have partly different advantages for different vehicle categories. This is presented in section 3.2 below.

3.2 Advantages and disadvantages

Section 3.1 described different options for converting conventional commercial vehicles to BEV or FCEV. All the options are relevant to all vehicle categories. However, different aspects may link to specific vehicle categories more so than to others. This varies based on the options described.

Basic technologies

If we summarise the analysis in section 3.1 but also screen the current market of conversion companies (see section 3.2), we can clearly see that only BEV, FCEV and, in future, maybe also electric roads are relevant technologies for now and for the future. For these technologies, the same advantages and disadvantages exist as for new locally emission-free vehicles. The ideal area of application for these technologies is heavily discussed in the literature (e.g. TRANSPORT & ENVIRONMENT, 2020 or HERRY CONSULT et al., 2021) and more broadly. The main facts are as follows:

- Energy efficiency versus possible travel distance:
  - BEV are more energy-efficient;
  - CAPEX and OPEX are lower for BEV;
  - FCEV have a greater travel distance (although OEMs have announced ranges of up to 500 km – 700 km for N3 BEV);
  - FCEV take less time to charge;
- BEV for short and medium distance and low and medium weight;
- FCEV for long distance and heavy vehicles.

For the conversion itself, BEV have some major advantages over FCEV:

- Most common e-motor technologies are for BEV not FCEV;
- There are more companies offering conversion to BEV (rather than FCEV);
- BEV conversion technologies are more advanced;
- Conversion kits exist for BEV (kits are still being developed for FCEV);
- Therefore, the BEV conversion capacity is higher;
- This leads to more competition on the BEV conversion market (compared to FCEV) and to more competitive prices.

These statements apply to all vehicle categories.

Conversion components

The main differences between the conversion components of BEV and FCEV are:

- BEV need a higher battery capacity and therefore more battery space, which means a higher vehicle weight and may reduce maximum loading weight;

- FCEV need additional components compared to BEV (battery management, fuel cell stack, fuel filler, hydrogen tank).

This is comparable to the situation for new vehicles and leads to the statements in the previous section. A cost comparison is difficult since BEV conversion is already more common and is starting to benefit from economies of scale, which is not yet the case for FCEV.

Conversion methods and organisational aspects

As mentioned above, conversion kits for FCEV do not exist yet. The existence of such kits is a prerequisite for competitive prices. As long as the conversion to FCEV is a "vehicle-by-vehicle" conversion without automation, the conversion to FCEV will be labour-intensive and the conversion capacities will be too low to achieve a (targeted) high number of conversions. The absence of conversion kits is hindering the development of partnerships between kit developers and the car workshops that execute the conversion. This is exacerbating the problem of low FCEV conversion capacity.

3.3 Overview of suppliers

Desktop research looking at existing companies offering the conversion of conventional commercial vehicles to locally emission-free technology was carried out. Given the findings regarding relevant basic technologies, this research focused on conversion to BEV and FCEV.

The research concentrated on the DACH region but was also extended to other countries (in Europe, the Americas and Asia).

Research template

A template was developed to structure the research. This template includes the following main topics gathered from the companies identified that offer conversion technologies for commercial vehicles:

- Company name;
- Country of company location;
- Contact details;
- Vehicle categories offered;
- Basic technology offered (BEV, FCEV – no other technologies offered);
- Status of technology (available on the market, test runs, in development, in planning);
- Type of integration (serial conversion, conversion kits, single conversion, special custom-made production);
- Battery performance;
- Distance range;
- Battery technology;
- Electric motor technology;
- Prices for conversion.

Conversion suppliers identified

The research carried out was broad but, of course, not all-encompassing. In total, 81 companies were identified and analysed:

- 30 companies from the DACH region (most of them in Germany; 4 of them in Austria);
- 24 companies from non-DACH European countries;
- 19 companies from the Americas (North, Central and South America; most of them in the USA);
- 8 companies from Asia (most of them in India).

Not all of the companies identified offer the conversion of commercial vehicles. Some companies only offer solutions for one vehicle category, others for different categories of commercial vehicle. The following list gives an overview of vehicle categories offered by the 30 companies identified in the DACH region (these companies are relevant for the conversion of vehicles from Austria):

- Cars only: 6 companies;
- N1 (LDV) (among others or exclusively): 19;
- N2 (HDV) (among others or exclusively): 15;
- N3 (HDV) (among others or exclusively): 13;
- M2+M3 (bus) (among others or exclusively): 8.

The research shows that the number of companies offering the conversion of freight transport vehicles decreases with the increase of vehicle size. Conversion companies do not distinguish between M2 and M3 buses.

Only a few companies offer serial production of conversion components and/or conversion kits:

- 24 of the 81 companies analysed produce their conversion components on a serial basis;
- 16 of the 30 DACH companies produce their conversion components on a serial basis;
- 15 of the 28 DACH companies offering commercial vehicles produce their conversion components on a serial basis;
- 6 of the 28 DACH companies give clear information about the conversion kit they offer.

Only those companies that produce their conversion components on a serial basis and/or offer conversion kits have the capacity for an extensive conversion operation or are able to build up conversion capacity in future. These companies are relevant for further analysis and were contacted and asked to complete a questionnaire about technical, legal and economic (cost and price) aspects.

Almost all of these 15 DACH companies offering the conversion of commercial vehicles on a serial basis offer the conversion to BEV:

- 12 companies offer BEV conversion only;
- 2 companies offer BEV and FCEV conversion;
- 1 company offers FCEV conversion only;

- At least 1 company develops a FCEV kit solution (besides the existing BEV kit solution).

A list of the 81 companies identified including the information using the template (for those companies that offered the information on their websites) represents the detailed outcome of this research (see Annex B – List of retrofit companies).

4 LEGAL FRAMEWORK

Vehicles that are to be (newly) registered on the European market must go through the European type-approval process. This grants permission to manufacture a vehicle, machine or device and place it on the market in accordance with the relevant technical requirements for manufacture (Certificate of Conformity). The legislation underpinning this process is Regulation (EU) 2018/858, which has replaced Directive 2007/46/EC since 30 May 2018. The main purpose of type-approval in this context is to ensure compliance with relevant legal principles with regard to vehicle and road safety, emission standards, environmental impact and the like. If a type-approved vehicle undergoes a technical conversion in the sense of a replacement of the drive unit (and the vehicle components that depend on it), the type-approval is no longer valid and the vehicle must go through the approval process again.

The large number of vehicles and vehicle models available means that this process of (extensive) individual approvals for technically converted vehicles involves a comparatively high level of effort and may be an obstacle to intensive vehicle conversion over the next 10 to 20 years.

"Eco-design"

This challenge could be partially mitigated at least if manufacturers of vehicles with internal combustion engines, for example, design and develop vehicles from 2030 onwards in such a way that their subsequent retrofitting involves as little retrofitting effort as possible and, at the same time, as little typification effort as possible. In this context, the term "eco-design" is used.

In addition, with regard to the legal framework, the question of warranty claims arises. Vehicle warranties are granted for a defined period of usually 2 to 7 years, are sometimes dependent on the mileage of the vehicle and usually expire the moment a vehicle is technically modified.

For the analysis of the legal framework, a list of all relevant national, European and international legal provisions that would be directly or indirectly affected by the retrofitting of vehicles was compiled first, by researching the literature. This included, but was not limited to, Regulation (EU) 2018/858 on type-approval and legal bases for warranties and product liability.

The questionnaire to retrofit providers also included questions on the legal framework. In addition, a few interviews were conducted with selected retrofit providers. Combining the results of the literature research with the answers of the retrofit providers offered a deeper understanding of the legal situation.

The documents identified were then analysed with regard to possible obstacles to the efficient and economical conversion of a large number of vehicles. Where necessary and possible, corresponding proposals for improvement were developed. We examined whether and in what form legislation could prescribe a sustainable product design ("eco-design").

The following questions were discussed in detail:

1. What impacts on and challenges for OEM warranty, warranty commitments and product liability are to be expected and, if necessary, how might the affected legal framework be improved?
2. What impacts on and challenges for type-approval requirements for converted vehicles are to be expected and, if necessary, how might the affected legal framework be improved?
3. What possible legal initiatives could be useful/necessary at European level (e.g. aspects of "eco-design") in order to facilitate the conversion of vehicles in the coming decades from a legal point of view?

4.1 Identification of the legal framework affected

Firstly, all the relevant national, European and international legal provisions that would be directly or indirectly affected by a vehicle conversion were identified.

4.1.1 National, European and international legal framework relevant to Austria

Table 1 gives an overview of these legal provisions identified.

Table 1: Overview of relevant legal provisions affected by the retrofitting of vehicles

ISO 26262	Road vehicles – Functional safety
IEC 61508	Functional safety of electrical/electronic/programmable electronic safety-related systems
ISO 15118	Road vehicles – Vehicle to grid communication interface
ISO 9001:2015	Quality management systems – Requirements
IATF 16949:2016	Automotive quality management systems
ISO 21498	Electrically propelled road vehicles – Electrical specifications and tests for voltage class B systems and components
ISO 6722-1	Road vehicles – 60 V and 600 V single-core cables – Party 1: Dimensions, test methods and requirements for copper conductor cables
ECE R10	Uniform provisions concerning the approval of vehicles with regard to electromagnetic compatibility
ECE R100	Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train
ECE R134	Uniform provisions concerning the approval of motor vehicles and their components with regard to the safety-related performance of hydrogen-fuelled vehicles (HFCV)
Regulation (EU) 2018/858	Regulation on the approval and market surveillance of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles

Regulation (EU) 2019/2144	Regulation on type-approval requirements for motor vehicles and their trailers, and systems, components and separate technical units intended for such vehicles, as regards their general safety and the protection of vehicle occupants and vulnerable road users (General Safety Regulation)
Regulation (EU) 2021/535	Commission Implementing Regulation laying down rules for the application of Regulation (EU) 2019/2144 as regards uniform procedures and technical specifications for the type-approval of vehicles, and of systems, components and separate technical units intended for such vehicles, as regards their general construction characteristics and safety
PHG	Austrian Product Liability Act *(Produkthaftungsgesetz)*
Directive 85/374/EEC	Directive on the approximation of the laws, regulations and administrative provisions of the Member States concerning liability for defective products
Directive (EU) 2019/771	Directive on certain aspects concerning contracts for the sale of goods
ABGB	Austrian Civil Code *(Allgemeines Bürgerliches Gesetzbuch)*

ISO 26262

ISO 26262 is an international risk-based safety standard for the functional safety of electrical and electronic systems that are installed in series production road vehicles, except for mopeds. This standard is a derivative of the safety standard IEC 61508 for the specific conditions of electrical/electronic systems in the automotive sector (ISO 26262-1:2018).

This standard is not to be applied to special vehicles that are usually manufactured in small series or one-off production. This standard is about potential risks that can be caused by the erroneous behaviour of E/E safety-related systems, including the interaction of these systems. The nominal performance of E/E systems is not addressed by ISO 26262 (ISO 26262-1:2018).

This standard is applied by automotive manufacturers and suppliers as well as testing institutes. Currently, there is no legal obligation to comply with ISO 26262 in development. In practice, however, almost all automotive manufacturers require the application of this safety standard for orders, as the standard also covers supplied components.

Moreover, the implementation of ISO 26262 is recommended for product liability reasons. The manufacturer has to develop and manufacture consumer products, e.g. road vehicles, according to the latest scientific and technical knowledge at the time of their launch on the market. In the event of a product liability lawsuit, compliance with ISO 26262 serves as a basis for demonstrating careful product development (SAULER, KRISO and HAFNER, 2011). Under the Austrian Product Liability Act, the burden of proof is reversed (*Produkthaftungsgesetz*, PHG; section 7), which means that the manufacturer has to prove “that the state of scientific and technical knowledge at the time when he put the product into circulation was not such as to enable the existence of the defect to be discovered” (Product Liability Directive, 85/374/EEC; Article 7e).

IEC 61508 IEC 61508 is an international standard with the title "Functional safety of electrical/electronic/programmable electronic safety-related systems". Regardless of the application and cross-sectorally, this standard is intended for application for the development of electrical, electronic and programmable electronic systems that perform safety functions. It is the parent standard of ISO 26262. On the one hand, the standard aims to facilitate the creation of product and sector-specific international standards. On the other hand, it aims to provide a framework for the development of those electrical, electronic and programmable electronic safety-related systems for which no product-specific or sector-specific standard exists (IEC 61508 standard).

ISO 15118 ISO 15118 is an international standard for the vehicle to grid communication interface in the electric charging of road vehicles. It contains specifications for the bidirectional communication between the electric vehicle and the electric vehicle supply equipment (EVSE), which not only enables the electric vehicle to be charged, but also allows electricity to be fed back into the grid. Moreover, it includes requirements and use cases for conductive and wireless high level communication (HLC). The latest edition of ISO 15118 also includes the new "Plug & Charge" feature, which means that all processes relevant to the charging are automated once the vehicle is plugged into the charging station (charging cards become redundant). The vehicle is identified and authorised automatically, and the billing is automated too. For this "Plug & Charge" feature, ISO 15118 also ensures IT security through encryption procedures and security certificates (HAGEMANN, 2022, ISO 15118-1:2019 standard).

This standard does not include any specifications for the internal communication between the vehicle's battery and other internal vehicle equipment (ISO 15118-1:2019 standard).

ISO 9001:2015 ISO 9001 is an international standard for quality management systems and specifies the requirements for such systems. This standard can be used by any organisation, regardless of the type of organisation, its size or the product provided. If an organisation complies with the requirements of this standard, it can receive a certificate to confirm this. The objective of this standard is to ensure that customers are provided with consistent, good-quality products and services (ISO 9001:2015).

IATF 16949:2016 Based on ISO 9001, IATF 16949 was developed for series production in the automotive industry, including some customer-specific requirements of the automotive sector. This standard aims to harmonise and combine all the important aspects of different assessment and certification systems worldwide in the supply chain of the automotive industry. Compared to ISO 9001, it sets more stringent requirements for the quality management system. IATF 16949 can be applied throughout the automotive supply chain for series production, spare parts manufacturing, assembly production, automobile manufacturers and other services in the automotive sector. As with ISO 9001, a company can be certified to IATF 16949 (TÜV SÜD, n.d.-a).

ISO 21498 ISO 21498 is an international standard with the title “Electrically propelled road vehicles – Electrical specifications and tests for voltage class B systems and components”. This standard is to be applied to voltage class B electric drive systems (from 30 to 1000 volts AC or from 60 to 1500 volts DC) of electrically powered road vehicles and electrical auxiliary units that are connected as well as to electrical circuits and components in these units. ISO 21498 provides definitions for sub-classes of voltage class B. It aims to standardise these sub-classes and component characteristics and to reduce varieties in order to lower the component and system costs. Moreover, it aims to decouple the design of voltage class B systems or components from the design of the electric energy source, thereby facilitating the exchange of components from different suppliers. The second part of ISO 21498 describes electrical tests for these electric and electronic components (ISO 21498-1:2021).

ISO 6722-1 ISO 6722 is an international standard that specifies the “dimensions, test methods and requirements” for 60V and 600V single-core cables of road vehicles. Part 1 of the standard deals with the specifications and requirements for copper conductor cables (ISO 6722-1:2011).

ECE R10 Regulation No 10 of the Economic Commission for Europe of the United Nations (UNECE) sets out “Uniform provisions concerning the approval of vehicles with regard to electromagnetic compatibility” (ECE R10). It addresses vehicles of categories L, M, N and O as well as components and systems that are intended for installation in these vehicles (ECE R10).

ECE R100 Regulation No 100 of the Economic Commission for Europe of the United Nations (UNECE) sets out “Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train” (ECE R100). Part I deals with safety requirements that need to be fulfilled by the electric propulsion systems of electric vehicles of categories M and N (passenger cars, buses and trucks; not vehicles with overhead lines) and by their high-voltage components as well as by galvanically connected systems. Part II deals with safety requirements that need to be fulfilled by the rechargeable energy storage system of these vehicles (ECE R100). It contains the specifications for all tests with lithium-ion batteries, which are installed in these electric road vehicles of categories M and N (TÜV SÜD, n.d.-b).

Batteries for electric and hybrid electric vehicles require approval by a national authority in order to be marketed in Europe. Therefore, testing according to ECE R100 is mandatory for these traction batteries (TÜV SÜD, n.d.-c).

ECE R134 Regulation No 134 of the Economic Commission for Europe of the United Nations (UNECE) sets out "Uniform provisions concerning the approval of motor vehicles and their components with regard to the safety-related performance of hydrogen-fuelled vehicles (HFCV)" (ECE R134). This regulation deals with the safety-related performance of hydrogen systems. It must be applied to compressed hydrogen storage systems that are intended for installation in hydrogen-propelled vehicles and to their specific components. Moreover, it must be applied to vehicles of categories M and N (passenger cars, buses and trucks) that are propelled with hydrogen (ECE R134).

Regulation (EU) 2018/858 Regulation (EU) 2018/858 deals with the "approval and market surveillance of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles" (Regulation (EU) 2018/858) and repeals Directive 2007/46/EC. This regulation specifies the essential technical and administrative type-approval requirements for vehicles of categories M, N and O (trailers) as well as for systems, components and separate technical units that are intended for installation in these vehicles. It can be considered the framework regulation for European type-approval (TÜV SÜD, 2022).

The objective of Regulation (EU) 2018/858 is to ensure that new types of vehicles comply with the safety and environmental protection requirements approved in the EU and to increase the level of quality and independence of the type-approval and testing. Moreover, the intention is also to harmonise the type-approval procedures and the conformity of production procedures applied by the authorities of the Member States and to make them more transparent. So, the tasks and responsibilities of all economic operators in the supply chain, of the authorities and parties involved in the type-approval process, are also clarified and defined in the regulation in order to guarantee the independence of these authorities and parties and to prevent conflicts of interest. The technical services, which are authorised by the EU Member States to test and inspect new vehicle models, are audited regularly and independently in accordance with the regulation. The national type-approval authorities are audited by the European Commission to ensure that the rules of the regulation are implemented and enforced throughout the EU. In order to usefully minimise the inspection effort within the scope of the type-approval procedure for serial vehicles, the inspections are usually carried out on the basis of vehicle samples. If the test executed on such samples of vehicles is passed, the manufacturer is permitted to manufacture any number of vehicles of the type-approved sample without having to subject each individual vehicle to an approval test (Regulation (EU) 2018/858, NARUISCH, DEGEN and LABZA, 2020).

By comparison with the former Directive 2007/46/EC, Regulation (EU) 2018/858 introduces extensively regulated sector-specific market surveillance. EU Member States have to carry out regular spot checks on vehicles already on the market, and if vehicles do not comply, they must take immediate protective measures. The regulation gives the European Commission significant power in the area of market surveillance. The Commission can perform market checks independently of the Member States and can give vehicle manufacturers administrative penalties of EUR 30,000 for every non-compliant vehicle (Regulation (EU) 2018/858, NARUISCH, DEGEN and LABZA, 2020).

A conversion kit can be deemed to be a system, component or separate technical unit according to Regulation (EU) 2018/858 and is therefore subject to the provisions of this regulation. So, it too has to be type-approved according to the procedures of Regulation (EU) 2018/858. In the case of retrofitting a vehicle, the provisions of "multi-stage type-approval" may apply (Regulation (EU) 2018/858, Article 22(3)). "In the case of multi-stage type-approval, manufacturers shall also be responsible for the approval and conformity of production of the systems, components or separate technical units that they have added at the stage of vehicle completion. Manufacturers who modify components, systems or separate technical units already approved at earlier stages shall be responsible for the type-approval and conformity of production of the modified components, systems or separate technical units. Manufacturers of the previous stage shall provide information to manufacturers of the subsequent stage regarding any change that may affect component type-approval, system type-approval or separate technical unit type-approval or the whole-vehicle type-approval." (Regulation (EU) 2018/858, Article 13(2)).

Regulation (EU) 2018/858 also prescribes that "vehicles, systems, components and separate technical units shall comply with the requirements of the regulatory acts listed in Annex II" (Regulation (EU) 2018/858, Article 5(1)). These regulatory acts also include ECE R10, ECE R100 and ECE R134 (see above).

Regulation (EU) 2019/2144

The new General Safety Regulation (GSR2), Regulation (EU) 2019/2144, sets out "type-approval requirements for motor vehicles and their trailers, and systems, components and separate technical units intended for such vehicles, as regards their general safety and the protection of vehicle occupants and vulnerable road users" (Regulation (EU) 2019/2144). This regulation updates the safety requirements for vehicles and especially focuses on those requirements that promise better safety for vulnerable road users (pedestrians and cyclists). Regulation (EU) 2019/2144 amends Annex II to Regulation (EU) 2018/858 in these respects. Moreover, this regulation allows the European Commission to adopt specific implementing acts for the type-approval of hydrogen-powered vehicles with regard to their hydrogen system, material compatibility and fuelling receptacles, and for the type-approval of hydrogen components (Regulation (EU) 2019/2144, Article 10(3)). This is ultimately realised by Regulation (EU) 2021/535 (see below).

Regulation (EU) 2019/2144 came into force on 6 July 2022 (Regulation (EU) 2019/2144).

Regulation (EU) 2021/535

Commission Implementing Regulation (EU) 2021/535 lays down "rules for the application of Regulation (EU) 2019/2144 [...] as regards uniform procedures and technical specifications for the type-approval of vehicles, and of systems, components and separate technical units intended for such vehicles, as regards their general construction characteristics and safety" (Regulation (EU) 2021/535). This regulation has been in force since 6 July 2022 and amends Regulation (EU) 2018/858 with regard to some aspects of hydrogen components. In the context of hydrogen-powered vehicles, this regulation deals with the safety performance and material compatibility of liquefied hydrogen storage systems and compressed hydrogen storage systems and specifies the procedure regarding the type-approval of hydrogen components (TÜV SÜD, 2022, Regulation (EU) 2021/535).

Austrian Product Liability Act (PHG)

The Product Liability Act transposes Directive 85/374/EEC into Austrian national law. According to this, product liability covers personal injury and property damage caused by defects that the product had when it was placed on the market. In the case of personal injury, this is compensated for regardless of whether a consumer or an entrepreneur is affected. Property damage, however, is only compensated for if the product is used privately. Moreover, product liability covers consequential damage, never the defective product itself (WKO, 2021-b).

A product is considered defective if it does not provide the safety that may be expected, taking all circumstances into account (Produkthaftungsgesetz, PHG; section 5). The general level of safety to be expected can be derived from the current state of scientific and technical knowledge at the time the product is placed on the market. In the case of EEA products, the manufacturer is liable for compensation for the damage; otherwise, liability rests with the first importer inside the EEA (*Produkthaftungsgesetz*, PHG; section 1).

Directive 85/374/EEC

Directive 85/374/EEC sets out the "approximation of the laws, regulations and administrative provisions of the Member States concerning liability for defective products", which is the basis for the national Product Liability Acts of the European Member States, including the Austrian Product Liability Act (Product Liability Directive, 85/374/EEC).

Directive (EU) 2019/771

Directive (EU) 2019/771 governs "certain aspects concerning contracts for the sale of goods" (Directive (EU) 2019/771). This directive forms the basis for the legally prescribed warranty.

ABGB section 922 et seq.

The statutory warranty for business-to-business-contracts (B2B) is regulated in Austria by the Austrian Civil Code (ABGB; section 922 et seq.). This obliges sellers/contractors to assume liability for product defects that already exist at the time of handover. This is obligatory and cannot be limited. The warranty period for moveable goods is 2 years from the time of handover. Within the scope of the statutory warranty, the liability is only for the product itself, not for consequential damage. In contrast to the warranty, the commercial guarantee is a voluntary promise and cannot restrict the statutory warranty (WKO, 2021-a).

ABGB section 1293 et seq.

Compensation for damage is also regulated by the Austrian Civil Code (ABGB; section 1293 et seq.). This concerns the legal liability of the seller/contractor for damage caused by a named person, and it includes both damage to the product itself and consequential damage. The prerequisite for compensation, however, is that there was at least slight negligence. Claims for compensation can be enforced in court at any time within 30 years. However, they must be brought within 3 years of knowledge of the damage and the damaging party (WKO, 2021-c).

4.1.2 Categorisation of the legal framework

As part of the overall concept of climate-friendly commercial vehicles, the German Federal Ministry for Transport and Digital Infrastructure (BMVI) set up an ad hoc task force to address the topic of retrofitting commercial vehicles (among other task forces for other topics). For this task force, the relevant players in the retrofitting sector were brought together and outstanding issues in the field of retrofitting were addressed. The objective was to develop cross-technological assessments and recommendations or technology-specific ones within the different alternative drive technologies (battery electric drives, fuel cell electric drives, hybrid overhead contact line drives). The focus was on discussing basic safety and quality standards for the conversion of commercial vehicles and bundling them into a criteria catalogue (BMVI, 2021).

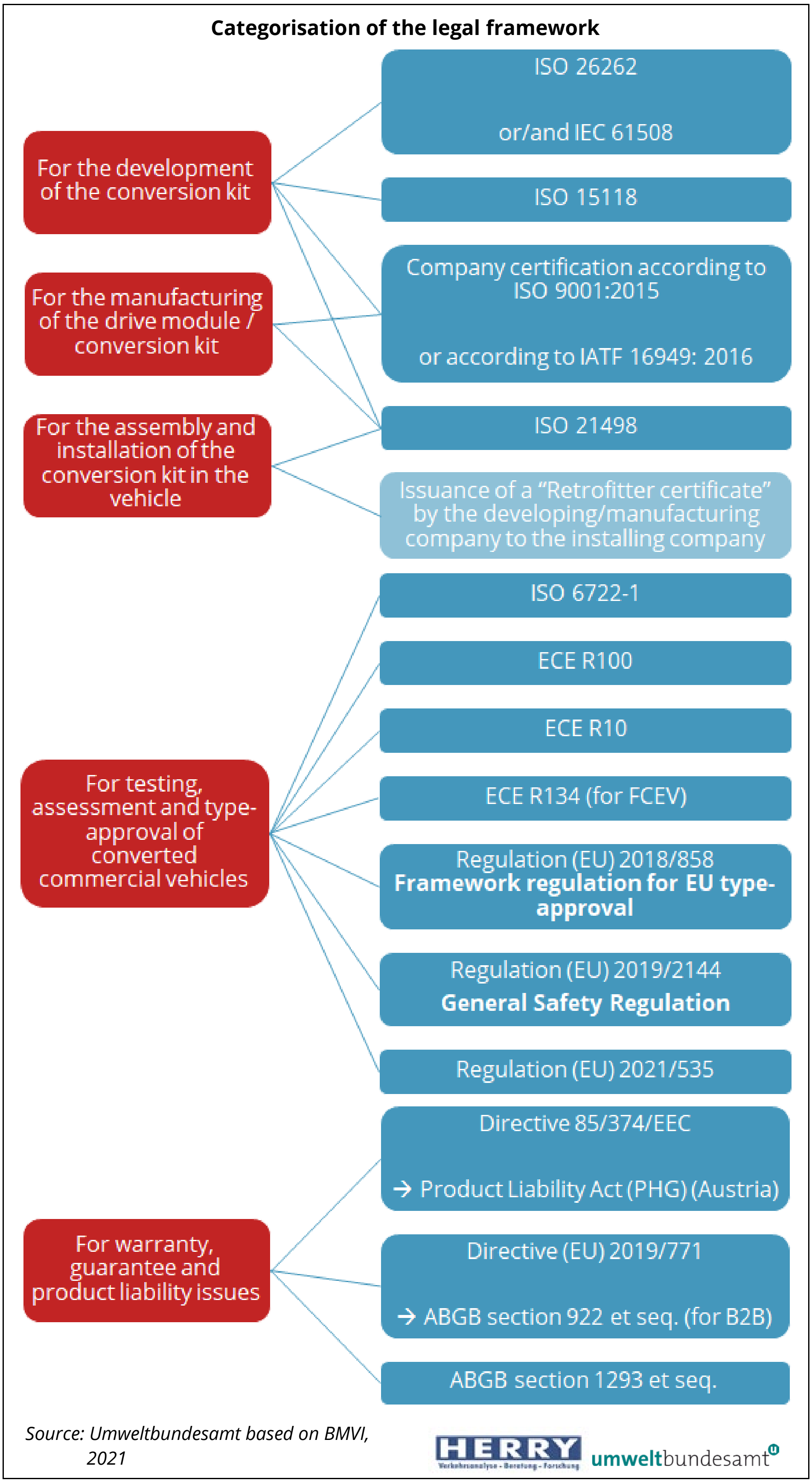
As business activities increase, the area of safety and quality standards for the retrofitting of commercial vehicles continuing to develop dynamically. Therefore, the criteria catalogue compiled by BMVI focuses on existing standards, norms and qualifications. Moreover, it has a special focus on battery electric vehicles and fuel cell electric vehicles. Since the retrofit process involves various stages of value creation, the criteria catalogue organises the essential standards to be met into categories according to these stages of the value chain (BMVI, 2021).

These categories are:

- Development of the conversion kit;
- Manufacture of the drive module / conversion kit;
- Assembly and installation of the conversion kit in the vehicle;
- Testing and assessment of converted commercial vehicles.

Based on this structure proposed by BMVI and extended by type-approval and by the category “warranty, guarantee and product liability issues”, the illustration as shown in Figure 3 was developed to provide a compact overview of the legal framework affected and the scope of application of the respective legal acts.

Figure 3: Categorisation of the legal framework affected by retrofit



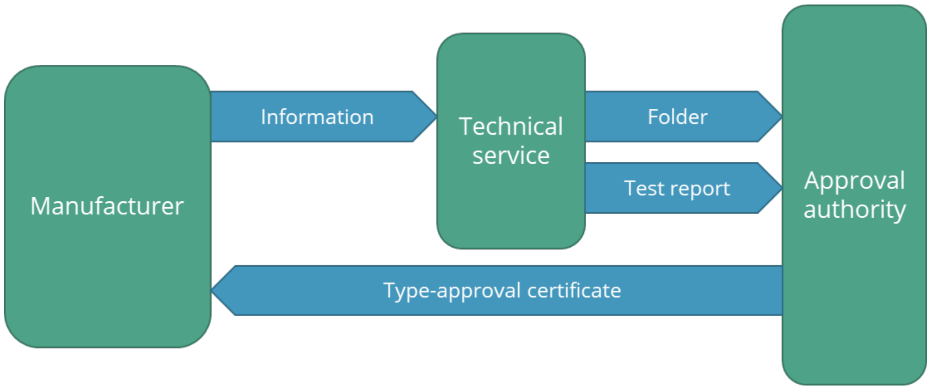
Source: Umweltbundesamt based on BMVI, 2021

4.1.3 Type-approval in the EU

Figure 4 illustrates the general type-approval procedure. Usually, the type-approval process in the EU is carried out by three stakeholders: the manufacturer, the authority of the approving country and a technical service (TÜV SÜD, 2022).

Figure 4: Type-approval process in the EU

Type-approval process



Source: Umweltbundesamt, based on TÜV SÜD, 2022

The technical services are authorised by the EU Member States to inspect and test new vehicle models. They are audited regularly and independently. If necessary, the EU Commission and other EU Member States can challenge the authorisation of the technical services. The national type-approval authorities in turn are audited by the EU Commission in order to ensure the same quality standards throughout the EU (EUR-LEX, 2021).

Usually, type-approval inspections and tests are carried out on vehicle samples. This minimises the inspection and testing effort as part of the approval procedure. The technical service in charge of the testing writes a test report according to regulatory requirements and in accordance with the respective test program and transmits this to the approval authority. If the vehicle type to be approved fully meets the requirements, the approval authority creates a type-approval certificate. This means that the manufacturer receives approval to produce any number of vehicles of this type (TÜV SÜD, 2022).

When applying for type-approval, the manufacturer can choose between different procedures: step-by-step type-approval, single-step type-approval, mixed type-approval and multi-stage type-approval (Regulation (EU) 2018/858, Article 22(1)). The most popular procedures are single-step and mixed type-approvals. In the single-step type-approval, the whole vehicle is approved at once. In the mixed type-approval, the whole set of EU type-approval certificates for the systems, components and separate technical units of a vehicle type is collected step by step, which finally results in the approval of the whole vehicle type (EUROPEAN PARLIAMENT, 2016).

For the approval of systems, components or separate technical units only the single-step type-approval is applicable. With complete vehicles that are modified or converted by another manufacturer after their completion, the multi-stage type-approval or the individual vehicle approval is required (Regulation (EU) 2018/858, Article 22(2) et seq., Article 47(1)). Accordingly, type-approvals for systems, components or separate technical units that are not modified remain valid until the expiration date for the first registration of the initial approval (Regulation (EU) 2018/858, Annex IX(3)). This also means that the manufacturer of the subsequent production stage bears no responsibility for items already approved during an earlier stage, unless relevant parts are modified by that manufacturer to such an extent that the type-approval previously granted becomes invalid (Regulation (EU) 2018/858, Annex IX(1)).

The provisions of Regulation (EU) 2018/858 are directly applicable in Austria due to its status as a regulation. Therefore, the provisions governing multi-stage type-approvals are also applicable in Austria. However, no EU type-approvals for motor vehicles are granted in Austria. The Austrian type-approval authority does not have the capacity to do so. In other EU Member States, such as Germany, Luxembourg, Spain, the Netherlands, Italy and France, the corresponding type-approval authorities grant type-approvals for motor vehicles.

4.1.4 Legal situation in different countries

Table 2 gives an overview of the legal situation regarding retrofitting in different countries, especially in the EU.

Table 2: Legal situation regarding retrofitting in different countries

Countries	Regulations regarding retrofitting
The USA, UK, Netherlands	• Only minor regulation of retrofitting
Austria, Germany, Italy, France, Belgium & other European countries	• Retrofitting is generally permitted, but with stricter regulations • Quality and safety standards ensured
Austria	• Only individual approvals possible
Germany	• Approval with type examination certificate (*Baumusterprüfbescheinigung*) is possible
Italy, France	• Special legal framework for approval of the conversion to battery electric or fuel cell electric drive

The USA, UK and Netherlands

The legal situation regarding retrofitting varies from country to country, even within the EU. In the USA, UK and Netherlands, the modification of vehicles is only slightly regulated. Any car owners can retrofit their vehicles without any real restrictions (or safety standards). According to representatives of the retrofit industry, quality and safety are not guaranteed by these rather loose regulations.

Austria, Germany, Italy, France and Belgium

In Austria, Germany, Italy, France and Belgium (possibly also more EU Member States), retrofitting is generally permitted but is subject to stricter rules than in the Netherlands, etc. According to representatives of the retrofit provider industry, Austria and Germany could serve as good practice for other EU countries. In Austria and Germany, it requires some effort to go through the approval process, but this ensures compliance with quality and safety standards. In Italy, a special regulation for approval of the conversion to battery electric or fuel cell electric drives exists (as is also the case in France, see next section); nevertheless, according to representatives of the retrofit industry, it seems to be a rather more complicated approval process than in Austria or Germany.

Difference between Austria and Germany

In Austria, the modified vehicle requires individual approval if the modifications concern essential technical characteristics of the type to which the vehicle belongs (Kraftfahrgesetz, KFG; section 33(2)). Changing the engine (and gearbox, etc.) to a different type (e.g. from ICE to electric motor) is considered an essential technical modification (Änderungserlass GZ. BMVIT-179.401/0004-IV/ST1/2015).

In Germany, modified vehicles do not necessarily require individual approval. If the retrofitted vehicle parts or retrofitted parts manufactured in series have a “General Operating Licence” (*Allgemeine Betriebserlaubnis*), not every single converted vehicle has to be approved individually (Straßenverkehrs-Zulassungs-Ordnung, StVZO; sections 22 and 20). Approval with a type examination certificate (*Baumusterprüfbescheinigung*) is possible, in contrast to Austria. According to representatives of the Austrian administration, the procedure in Germany is not necessarily less burdensome than the procedure in Austria (Kraftfahrgesetz, KFG; section 33) if the proof of conformity of the modifications is provided through a type-approval certificate for the (retrofitting) parts used.

4.1.5 Special legal situation in France

The research identified a special legal situation in France regarding the conversion of vehicles. Until 2020, it was very difficult to retrofit vehicles in France in comparison to other European countries like the UK, Germany, Italy and Belgium, according to representatives of the French retrofit industry. A regulation from 1954 imposes authorisation by the original vehicle manufacturer for every single vehicle that is modified somehow, regardless of the type of modification (including retrofitting). Moreover, the procedure was expensive and complex, making the process lengthy and difficult, which discouraged any industrial and commercial activity. Therefore, the French state together with stakeholders of the French retrofitting sector (mainly the members of the AIRE association) worked out a special regulation for the conversion of vehicles with internal combustion engines into electric vehicles. According to representatives of the French retrofit industry, the goals of this regulation were:

- to set up a genuine French industry for retrofitting an electric propulsion system (AIRE, n.d.);
- to maintain high quality and safety standards;

- to define the responsibilities and links between the conversion kit manufacturer, the installer and the national vehicle approval centre.

French regulation governing retrofitting electric motors from March 2020

So, the regulation governing "the conditions for converting vehicles with internal combustion engines into battery or fuel cell electric motors" was published on 13 March 2020 and entered into force on 4 April 2020 (Decree TRER2007140A).

This regulation permits the conversion from ICE to a battery electric or fuel cell electric propulsion system if the vehicle meets the following conditions:

- Vehicles of categories M and N, older than 5 years (based on the date of initial registration);
- Vehicles of category L, older than 3 years;
- Registered in France in a definitive series;
- Not registered as a classic/vintage vehicle.

According to the regulation, only installers operating in the territory of France and authorised by the manufacturer of the conversion kit can carry out the retrofitting. An installer can be licensed for one or more types of vehicle. The manufacturer of the conversion kit issues an installer's permit for a maximum of 2 years, then it has to be renewed (Decree TRER2007140A).

The official homologation body in France is the *Union Technique de l'Automobile, du motocycle et du Cycle* (UTAC). Authorisation by the UTAC according to this new regulation is not individual authorisation but series approval. So, once the retrofit of a vehicle type has obtained series approval, the same type of vehicle can be retrofitted as often as required without new authorisation by the UTAC.

In accordance with the regulation, the manufacturer of the conversion kit guarantees the preservation of the integrity of all the components of the converted vehicle. The manufacturer must assume responsibility for any deterioration to any components of the converted vehicle and any part that could be affected or damaged by the retrofit and must demonstrate its performance (Decree TRER2007140A).

Table 3 gives an overview of some of the technical obligations established by the French regulation.

Table 3: Technical obligations under the French retrofit regulation (Decree TRER2007140A)

Power of the electric drive train	• Must be within the range of 65 % - 100 % of the maximum power of the original ICE • For vehicles of categories L1e and L5e: within the range of 40 % - 100 %
Vehicle dimensions	• Dimensions of the original vehicle (length, width, height, wheelbase, overhang, tracks, etc.) must not be altered by the retrofit
Gross vehicle weight	• Must not be altered by the retrofit
Maximum permissible load on each axle	• Must not be altered by the retrofit

Unladen weight of vehicle	• Must not change by more or less than 20 %
Distribution of the unladen weight between the axles	• Must not change by more than 10 %

The regulation was mainly written for vehicles of categories M1 and N1. According to representatives of the French retrofit industry, the challenge for the future is to adapt it for heavy-duty vehicle stakes and specificities too.

Regulations in Spain and Belgium under discussion

The French regulation is based on a similar Italian legal regulation from 2015, but this text was not further examined in this study (*Decreto Retrofit*, D.M. n. 2019/15). In Spain and Belgium, there are also debates as to whether a regulation based on the French and Italian examples makes sense and as to how such a regulation should be designed. While a future regulation in Spain will probably be set up rather along the lines of the French model, a different path is preferred in Belgium: single vehicle approval and the authorisation of the original vehicle manufacturer.

4.2 Identification and explanation of the obstructive aspects

Strong differences between the legal frameworks in different EU countries

The above differentiation between the legal situations in the different countries already shows that there are no uniform conditions or legal frameworks regarding retrofitting, neither worldwide nor in the Member States of the European Union. Here, OEMs as well as retrofit providers have a choice between 27 different type-approval authorities and more than 300 technical services (EUROPEAN PARLIAMENT, 2016). To date, the homologation processes in the EU countries have differed widely. Moreover, the legal situation regarding the (type-)approval of retrofitted vehicles is often complex and non-transparent. In some EU countries, approval for modification is not possible at all or only available with the authorisation of the OEM. According to representatives of the retrofit industry, the homologation process often depends a lot on the technical service. The decisions of the technical services are often very individual, partly because the conversion from ICE to electric drive is still not an everyday business for the technical services.

The non-uniform regulations across the EU regarding retrofitting are an obstacle to the conversion of a large number of commercial vehicles.

In Austria, only individual approvals of converted vehicles are possible so far. This could hinder a rapid and economical conversion of significant quantities of vehicles. Retrofit industry representatives see more need for action than the Austrian administration and legislator. The industry is already seeking good framework conditions in order to accelerate the ramp-up of the technology, while the administration would prefer that the legislator reacts to the current requirement. However, both see the need for a uniform solution under European law.

In France, a retrofit can only be carried out by installers in the territory of France, which works against the establishment of an EU-wide retrofit market. It favours individual national regulations instead of promoting an EU-wide solution. On the other hand, according to representatives of the French retrofit industry, this also prevents converted vehicles from being transported over long distances to their final place of use, which in turn generates additional CO_2. The French approach thus emphasises regional value creation. Another obstructive aspect in France is that type-approval is relatively costly there. According to representatives of the French retrofit industry, the certification itself costs around EUR 200,000, which includes all the battery tests and electromagnetic testing, etc.

Example: different permissible axle loads across the EU

How different the legal provisions are in the individual EU Member States can be illustrated with a specific example. The permissible axle load varies in the EU countries, although Directive 96/53/EC provides harmonised rules on axle loads to which Member States must adhere as a minimum (Directive 96/53/EC). However, individual Member States may also allow higher axle loads. In the Netherlands, for example, higher axle loads are permitted, even though the same vehicle types operate there. The axle load is a relevant aspect for the retrofit as the axle load changes depending on the position of the battery system. An EU-wide solution is necessary here.

Product liability

During the research, the question arose as to whether the issue of product liability could be an obstacle to retrofitting vehicles. However, in this area no relevant obstructive aspect was identified, neither in Germany (where no specific retrofit regulation exists) nor in France (where a specific retrofit regulation exists).

Product liability was indeed an issue in the drafting of the French regulation for retrofitting an electric drive. According to the regulation, the manufacturer of the conversion device must guarantee the preservation of the integrity of all parts of the converted vehicle. The manufacturer must assume responsibility for any damage to any component of the converted vehicle and any part that may be in contact with or damaged by the electrical conversion device (Decree TRER2007140A). This means that the conversion device manufacturer is only responsible for the converted parts while the OEM remains responsible for the parts not affected by the retrofit.

Although there is no specific retrofitting regulation in Germany, product liability for converted vehicles works in the same way as in France. In fact, the same rules apply as for the first placement of a vehicle on the market. The person who places a component on the market is liable for defects. In the event of damage (personal injury or damage to property) caused by a defect, the customer contacts the retrofitter, who in turn – as part of the product liability chain – contacts the original manufacturer of the defective component. This means that the retrofitter is only liable for those components/units that were touched during the retrofit or that are part of the conversion kit. If, for example, a vehicle brake fails after retrofitting, but the failure is not due to the retrofit, the brake manufacturer is liable for the damage, not the retrofitter. The same applies for Austria.

In this context, development in accordance with ISO 26262 is crucial, as compliance with ISO 26262 serves as the basis for demonstrating careful product development (see 4.1.1).

Commercial guarantee by the OEM

In contrast to the statutory warranty according to ABGB section 922 et seq. (see 4.1.1), the commercial guarantee is a voluntary promise by the OEM. In the case of commercial vehicle sales, the scope and duration of this commercial guarantee vary greatly between the different manufacturers and depend on the package ordered. This commercial guarantee expires when a vehicle is converted, which is an obstacle to the conversion of vehicles that are still within their warranty period.

4.3 Suggestions for improvement

Uniform legal framework in EU

It is recommended that a regulation be introduced at EU level specifically for the conversion of vehicles to locally emission-free drive technologies and for the corresponding type-approval. The objective of such a regulation should be to create uniform conditions and legal frameworks regarding retrofitting. This regulation could be based on the French regulation as a good example and on good practices in Germany and Austria. It should include strict quality and safety standards. Moreover, the regulation should not only focus on vehicles of categories M1 and N1 (as in France), but especially on heavy-duty vehicle stakes and specificities. The goal should be to establish a European conversion market that enables the rapid and economical conversion of significant quantities of vehicle series. It should also still be possible to approve individual vehicles.

Reasonable costs

The type-approval of converted vehicles should not be associated with excessive costs. Certification costs that are too high would prevent the economical conversion of significant quantities of vehicles.

No confinement to installers in national territory

There should be no confinement to installers in the national territory, as is the case in France. This would work against the establishment of an EU-wide retrofit market. So, it is recommended that the regulation on retrofitting indicates that the conversion of a vehicle can be carried out in any EU Member State by any installer who is certified.

Uniform knowledge in the technical services

It is recommended that uniform knowledge be established in different technical services with regard to the retrofit and uniform testing and approval procedures. In this context, use of the “Forum for Exchange of Information”, which was introduced with Regulation (EU) 2018/858, is recommended so that information can be exchanged between the EU countries and their technical services regarding retrofitting. However, it should be noted that the Forum deals only with issues of interpretation and application of the Framework Regulation. This means that the regulations on retrofitting would have to be set out in the Framework Regulation beforehand.

Technical aspects

When introducing a regulation specifically for the conversion of vehicles to locally emission-free drive technologies, the following technical aspects should be considered:

According to representatives of the retrofit industry, the external vehicle dimensions should be a bit more flexible and should not have to remain absolutely the same for a converted vehicle as in the original vehicle. For instance, this would mean that the heat exchanger or hydrogen tank could be installed on top of the vehicle. It is important that the centre of gravity stays at the same vertical level or lower and that the maximum dimensions according to Directive 96/53/EC or Regulation (EU) 2021/535 are complied with (Directive 96/53/EC, Regulation (EU) 2021/535).

Flexibility regarding the axle weight and the ratio between the axle weights would be helpful. According to representatives of the retrofit industry, the weight on the rear axle is often right at the axle's limits after the retrofit.

With regard to the payload, it is also recommended that the restrictions are loosened slightly. The maximum speed could be reduced a little (as compensation) in order to increase the permitted payload and still ensure safety standards. For instance, the Renault Maxity (nearly identical to Nissan Cabstar, same drive train, manufactured on the same production line) is a light commercial vehicle, available from 2.8 to 4.5 tonnes, which is used in many French cities. The top body and payload carrying capacity is 1.8 tonnes in total. Depending on the top body, between 300 and 400 kilograms remain for the payload. If this vehicle is retrofitted with an additional 200 kilogram battery, there are only 100 to 200 kilograms of payload left. Here, the permitted payload should be increased somewhat, otherwise the retrofit holds no appeal for this vehicle category, according to representatives of the retrofit industry.

4.3.1 Process for the development of a criteria catalogue at national level

In Germany, the BMVI set up an ad hoc task force to address the topic of retrofitting commercial vehicles. More than 60 industrial players were involved in this task force, mainly companies and institutions that deal with the retrofitting of commercial vehicles, their testing or assessment and approval as well as with the development and manufacturing of conversion kits. In addition, the (potential) users of converted vehicles were involved in the process. The central concern of the task force was to create a common understanding of fundamental safety and quality standards throughout the value chain for retrofitting vehicles – from development to approval (Klimafreundliche Nutzfahrzeuge, 2021).

The task force began in February 2021 with an expression of interest procedure. Subsequently, stakeholders of the retrofit industry were able to submit proposals for relevant minimum standards regarding product and manufacturing quality by completing an online survey. The stakeholders were then invited to four online workshops in March 2021 where the proposals of the respective phase of the value chain were presented. For all the criteria presented, the stakeholders' positions were heard, discussed and documented with regard to the quality impact and feasibility of these criteria. As a core result of the task force, the BMVI drew up a criteria catalogue from those criteria recommended by a clear majority and presented it at a final event. This criteria catalogue and further recommendations serve as a guide for companies of the retrofit industry and for potential clients wanting to procure converted vehicles. The catalogue provides an overview of tried and tested standards at all stages of the retrofitting process (Klimafreundliche Nutzfahrzeuge, 2021).

Bringing retrofit stakeholders around the table

The retrofit task force not only produced a criteria catalogue; even more important was the fact that this was the first time stakeholders in the retrofit industry had networked with each other. Therefore, as a first step, it is recommended that Austria launch a similar process to that in Germany in order to establish a network of stakeholders operating in the retrofit industry.

5 QUANTITY STRUCTURE, GHG REDUCTION & LIFE CYCLE ASSESSMENT

New registration targets in the EU and in Austria

According to the "Fit for 55" climate and energy package, the CO_2 emissions of newly registered passenger cars (PC) and light commercial vehicles (LCV) should be reduced by 55 % from 2021 to 2030. By 2035, only zero-emission vehicles should be newly registered in these vehicle categories. In the HDV sector, the CO_2 emissions should be reduced by 30 % from 2019 to 2030.

According to Austria's more ambitious Mobility Master Plan, 100 % of all new car and two-wheel, LCV and HDV (under 18 tonnes) registrations will be zero-emission by no later than 2030 and 100 % of all new bus registrations will be zero-emission by 2032. By 2035, 100 % of all new HDV over 18 tonnes will be zero-emission.

Mileage and vehicle lifespan

The above-mentioned vehicle categories have different specific annual mileages, which generally decrease with the age of the vehicle. The useful life of a vehicle in Austria depends on numerous variables and averages 10 to 15 years (UMWELTBUNDESAMT, 2021-a), depending on the vehicle category.

Only new registration targets are not enough

A comparison between the above-mentioned new registration targets and the average useful life of a commercial vehicle shows that the time span between the new registration targets and the goal of climate neutrality according to Austria's Government Programme is too short to ensure climate neutrality in 2040 through the measure of new registration of zero-emission vehicles alone. It can be assumed that in 2040 (without additional accompanying measures) there will still be a significant old stock of vehicles with ICE.

Estimation of the potential of retrofitting

In this work package, the ConVErT study aimed to quantify these vehicle volumes, especially in the area of vehicles used commercially, using the EAA fleet model. From this remaining vehicle volume with ICE, the size of the potential for retrofitting with zero-emission drive technology could be derived directly. From this, in turn, the possible greenhouse gas emission reduction through retrofitting could also be derived.

5.1 Calculation of the vehicle stock

This section begins with a description of the methodology for calculating the remaining vehicle stock with ICE by 2040. It then illustrates the results of the calculation and derives the potential for retrofitting with zero-emission drive technology.

5.1.1 Methodology for calculating the vehicle stock

EAA fleet model

The Excel-based fleet model of the Environment Agency Austria was used to estimate how many vehicles could in principle be subject to vehicle conversion. This was calculated separately for the vehicle categories M1, M2 and M3, N1, N2, N3 and semi-trailers. The fleet model uses as input data:

- historical data regarding the vehicle stock and new vehicle registration figures;
- assumed absolute new vehicle registration figures from 2022 to 2050;
- empirically proven failure probabilities in the Austrian vehicle fleet based on the Network Emission Model;
- assumed vehicle stock development from 2022 to 2050.

The vehicle classes M2 and M3 are combined into one category, as the historical data regarding vehicle stock and new vehicle registrations are only available for these two classes together.

As the new registration targets differ between the EU and Austria, modelling with the fleet model was performed for each of the above vehicle categories for two scenarios:

- a **"low scenario"** with assumed absolute new registration figures according to the European targets (less ambitious targets according to "Fit for 55");
- a **"high scenario"** with assumed absolute new registration figures according to the Austrian targets (more ambitious targets according to Austria's 2030 Mobility Master Plan).

Table 4 is a comparison between the "low scenario" and the "high scenario". At the time, the study was conducted, the cells framed in red did not have a defined target year yet according to the corresponding legal provisions (at European or Austrian level); these are only assumed for the definition of scenarios in ConVErT.

Table 4: Target years by when only zero-emission vehicles should be newly registered in the specific vehicle category

Vehicle category	"Low scenario"	"High scenario"
Passenger cars (M1)	2035	2030
Light commercial vehicles (N1)	2035	2030
Heavy-duty vehicles ≤ 12 tonnes gross vehicle weight (N2)	2035	2030[1]
Heavy-duty vehicles > 12 tonnes gross vehicle weight (N3)	2040	2035[1]
Semi-trailers	2040	2035
Buses (M2 & M3)	2032	2032

[1] Weight limit at 18 tonnes gross vehicle weight according to target provisions

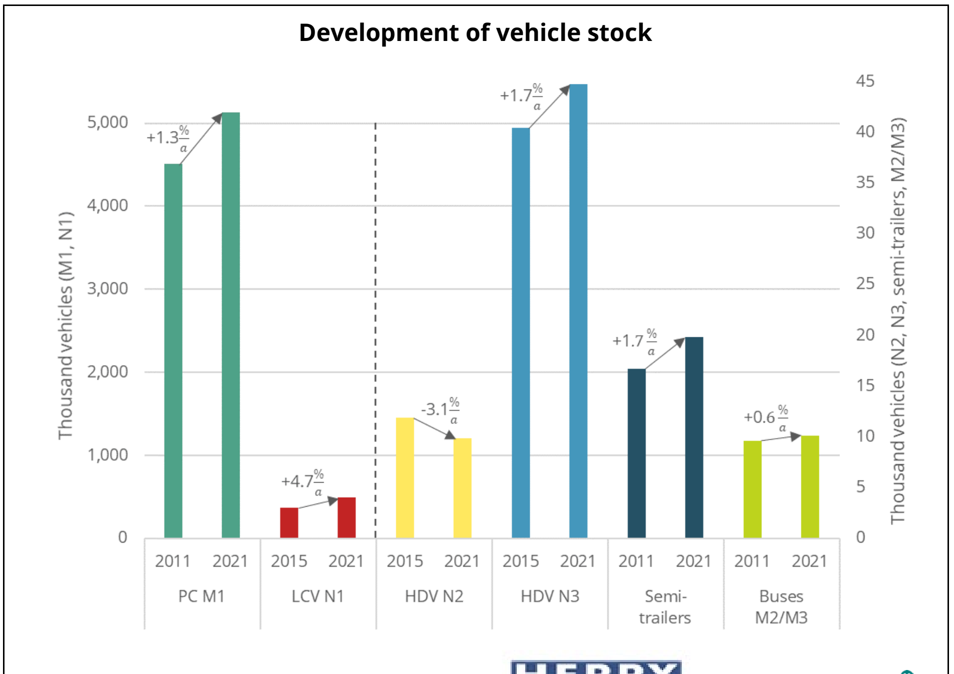
However, it is important to state that the **"high scenario" refers to Austria's 2030 Mobility Master Plan only in terms of the target years for new zero-emission registrations.** No other elements of the Mobility Master Plan were adopted. **Therefore, the fleet development assumed** hereafter in the study is **not consistent with that in the Mobility Master Plan.**

Furthermore, the possible technology shares were derived from the new registration targets. For vehicle category M1, the percentage of e-vehicles grows linearly to 100 %, while for the other vehicle categories the percentage of e-vehicles grows exponentially. The calculations do not differentiate between different zero-emission propulsion technologies (fuel cell electric and battery electric). The vehicles are grouped under "electrically powered vehicles".

The statistical distribution for vehicle failure as a function of vehicle age is taken from the Network Emission Model. This model is used, among other things, to calculate the Austrian greenhouse gas and air pollutant inventory as well as to calculate the official Austrian climate and energy scenarios of different ambition levels.

The assumption regarding the development of the vehicle stock was based on an analysis of historical data. Figure 5 illustrates the development of the vehicle stock from 2011/2015 to 2021 for the different vehicle categories. For all vehicle categories except category N2, there is an annual increase in the vehicle stock. From 2011 to 2021, the average annual increase for passenger cars stands at 1.3 %, for semi-trailers at 1.7 % and for buses at 0.6 %. From 2015 to 2021, the average annual increase for LCV (N1) stands at 4.7 % and for HDV of category N3 at 1.7 %. Only HDV of category N2 show an average annual decline of 3.1 % from 2015 to 2021. The different reference years were chosen due to data availability.

Figure 5: Development of vehicle stock in Austria



Source: Umweltbundesamt

If the vehicle stock were to continue to increase at this rate in the coming years, there would be, for example, over 6.6 million passenger cars and over 1.3 million LCV in Austria in 2040. This is not plausible. Further measures will be taken to reduce vehicle growth. Therefore, lower growth rates were assumed for 2022 to 2050, as shown in Table 5.

Table 5: Assumptions for annual growth rates by vehicle category for 2022 – 2050 and absolute vehicle stock in 2040

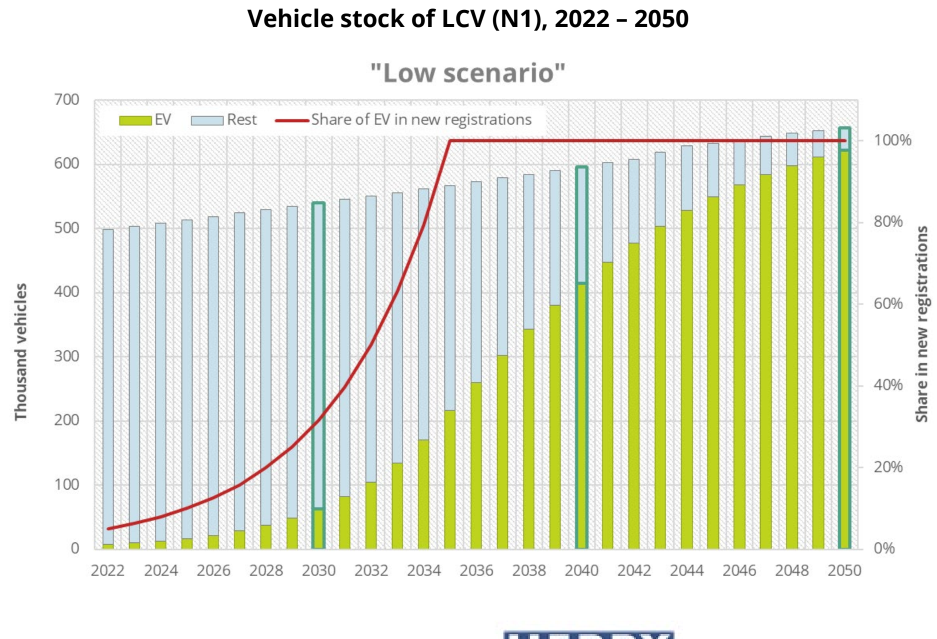
Vehicle category	**Assumed growth rate 2022 - 2050**	**Assumed vehicle stock in 2040**
Passenger cars (M1)	+0.5 % p.a.	5,644,100
Light commercial vehicles (N1)	+1.0 % p.a.	596,100
Heavy-duty vehicles ≤ 12 tonnes gross vehicle weight (N2)	-0.5 % p.a.	9,000
Heavy-duty vehicles > 12 tonnes gross vehicle weight (N3)	+0.5 % p.a.	49,200
Semi-trailers	+0.5 % p.a.	21,800
Buses (M2 & M3)	+0.5 % p.a.	11,100

A time series for the fleet composition was then derived from the link between stock figures, new registration figures and the default probabilities. This provides information on how many vehicles with ICE in the above-mentioned vehicle categories will still be in the Austrian vehicle fleet in 2040 and could therefore potentially be considered for retrofitting.

5.1.2 Results of the calculation of the vehicle stock

Figure 6 illustrates the time series for the fleet composition of LCV (N1) from 2022 to 2050 assuming the “low scenario” according to EU targets. The light green bars represent the absolute numbers of electric LCV. The light blue bars represent the remaining conventional vehicles with ICE in the LCV fleet. The red line shows the percentage share of electric LCV in new registrations. In the “low scenario”, 100 % is reached in 2035. In 2040, there are still around 181,000 LCV with ICE in the fleet.

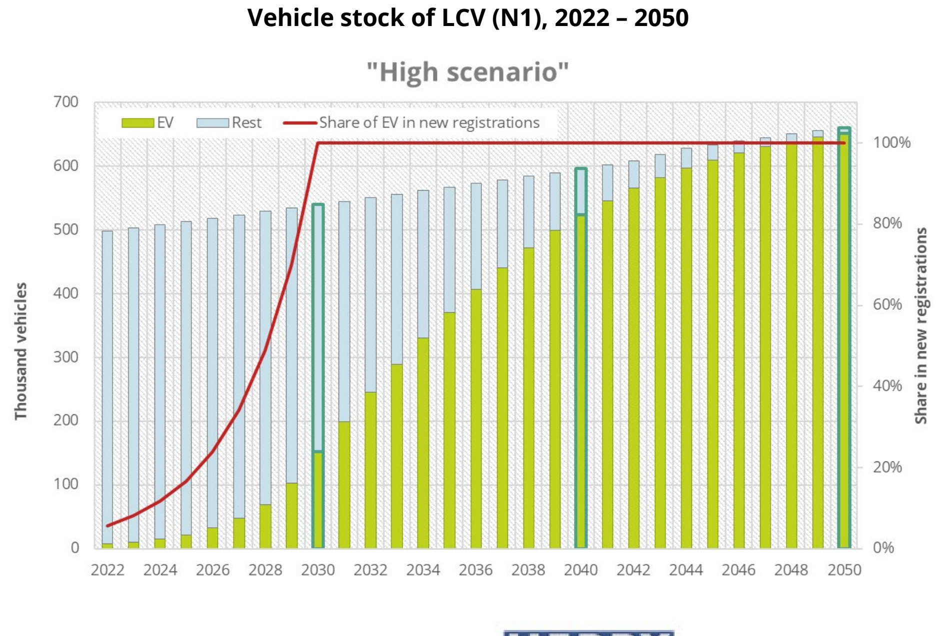
Figure 6:
Time series for fleet composition of vehicle category N1 for 2022 – 2050 for the "low scenario"



Source: Umweltbundesamt

Figure 7 illustrates the time series for the fleet composition of LCV assuming the "high scenario" according to Austria's targets. Here, 100 % of electric LCV in new registrations is already reached in 2030. Therefore, in 2040 there are only around 72,100 remaining LCV with ICE in the fleet.

Figure 7:
Time series for fleet composition of vehicle category N1 for 2022 – 2050 for the "high scenario"



Source: Umweltbundesamt

The illustrations for the other commercial vehicle categories (N2, N3, M2 & M3, semi-trailers) can be found in Annex C – Time Series for Fleet composition.

Table 6 gives an overview of the remaining vehicles with ICE in 2040, by vehicle category, comparing the “low scenario” with the “high scenario”.

Table 6: Remaining vehicles with ICE in vehicle stock in 2040, by vehicle category

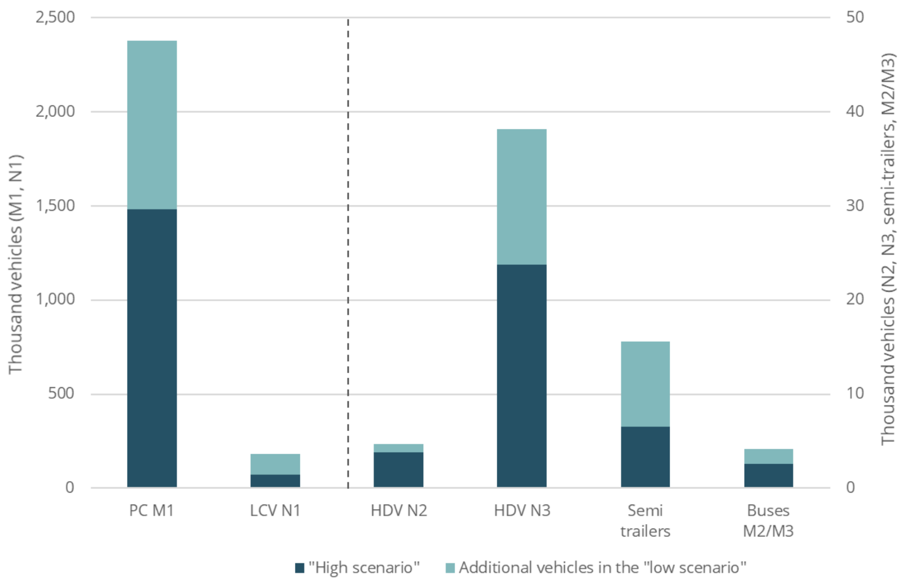
Vehicle category	“Low scenario”	“High scenario”
Light commercial vehicles (N1)	181,000	72,100
Heavy-duty vehicles ≤ 12 tonnes gross vehicle weight (N2)	4,700	3,800
Heavy-duty vehicles > 12 tonnes gross vehicle weight (N3)	38,200	23,800
Semi-trailers	15,600	6,500
Buses (M2 & M3)	4,100	2,500

The potential for retrofitting is more than 100,000 commercial vehicles

As the “high scenario” sets an earlier phase-out of new registrations of vehicles with ICE, a total of 39 % fewer vehicles with ICE remain in the fleet in 2040 when comparing the “high scenario” with the “low scenario”. Even with the more ambitious targets according to the “high scenario”, there is still a huge number of vehicles with ICE in Austria’s fleet: almost 1.6 million vehicles. This is the potential number of vehicles that could be converted to zero-emission propulsion systems. Of these, more than 100,000 are commercial vehicles.

Figure 8: Remaining stock of conventional vehicles with ICE in 2040

Remaining stock of conventional vehicles with ICE in 2040, comparison between “low scenario” and “high scenario”



Source: Umweltbundesamt

Figure 8 illustrates the number of conventional vehicles with ICE that remain in the fleet in 2040, by vehicle category. The dark blue bars show the numbers for the “high scenario”. The light blue bars represent the vehicles that additionally remain in the fleet in the case of the "low scenario". This figure also includes the category of passenger cars, which is discussed in detail in section 8.2.1.

However, it must be emphasised again that **these calculations are not consistent with the fleet development on which Austria's 2030 Mobility Master Plan** is based.

5.2 Estimation of the potential for GHG reduction

This section begins with a description of the methodology for estimating the potential for GHG reduction from retrofitting. It then illustrates the results of this estimation.

5.2.1 Methodology for estimating the potential for GHG reduction

Calculation of GHG reduction potential

The GHG reduction potential was calculated for each vehicle category with the input parameters of the remaining vehicle stock with ICE until 2040, the corresponding emission factor and the annual mileage.

Annual mileage

For the annual mileage, the data from 2019 were used, as the data from 2020 were very much influenced by the Covid-19 pandemic and were below the average of recent years. There were no specific data available for the category of M2/M3 buses. In the emission factors of the Environment Agency Austria, a distinction is only made between travel buses and line buses. Thus, the average of these two was used for M2/M3. Moreover, at the Environment Agency Austria, the subdivision of HDV is not at 12 tonnes gross vehicle weight (as per the vehicle class definition for N2 and N3), but at 18 tonnes. However, this only results in a slight blurring in the calculations. It was assumed that the specific mileage would remain the same as in 2019 until 2040.

Table 7: Annual mileage by vehicle category in 2019 (Umweltbundesamt, 2021-b)

[km p.a.]	PC M1	LCV N1	HDV N2 [1]	HDV N3 [2]	Semi-trailers	Buses M2/M3 [3]
2019	13,700	17,900	89,900	66,900	76,900	48,600

[1] ≥3.5 tonnes and <18 tonnes,
[2] ≥18 tonnes,
[3] average of travel buses and line buses

Emission factors

For the emission factors, the data from the Handbook Emission Factors for Road Transport (HBEFA) for 2040 were used, as listed in Table 8. For the category of M2/M3 buses, the same applies as explained above. However, the subdivision of HDV (N2 and N3) is at 12 tonnes gross vehicle weight. The emission factors are given in grams of CO_2 equivalents per vehicle kilometre. They only include the direct emissions during vehicle operation.

Table 8: Emission factors by vehicle category in 2040 (Umweltbundesamt, n.d.)

[g CO_{2e}/ vkm]	PC M1	LCV N1	HDV N2 [1]	HDV N3 [2]	Semi-trailers	Buses M2/M3 [3]
2019	132.9	156.3	316.6	516.1	671.7	547.4

[1] *≥3.5 tonnes and <12 tonnes,*
[2] *≥12 tonnes,*
[3] *average of travel buses and line buses*

With these input parameters the GHG emission reduction potential is calculated as follows:

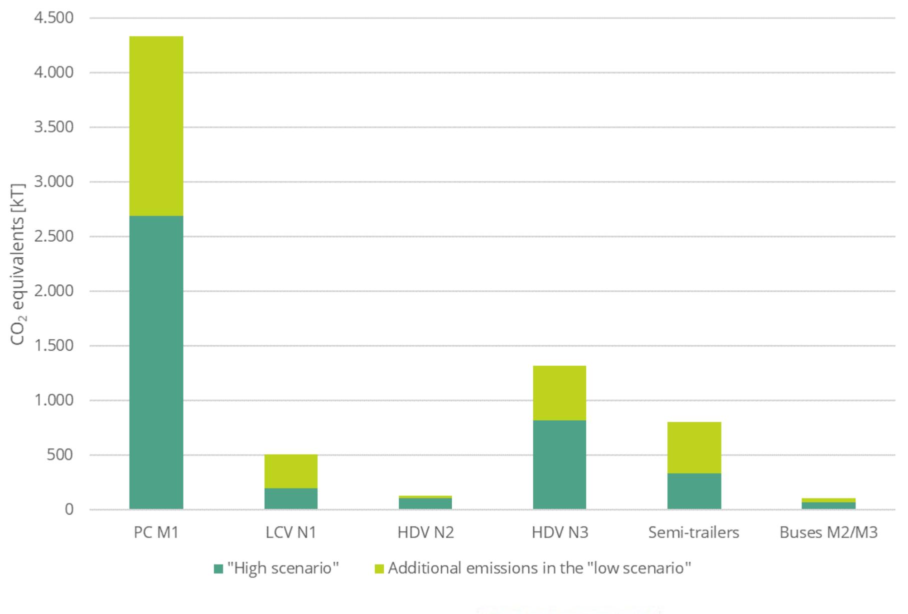
$$GHG\ reduction\ potential = \sum_{i=M1}^{M2/M3}\left(Remaining\ ICEV\ stock_{2040_i}\cdot\left[\frac{g\ CO_{2_{equ}}}{vkm}\right]_{2040_i}\cdot mileage_{2019_i}\right)$$

$$i \in \{M1; N1; N2; N3; semi\text{-}trailers; M2/M3\}$$

5.2.2 Results of the estimation of the potential for GHG reduction

Figure 9 shows the potential GHG emissions from the remaining stock of conventional vehicles in 2040 by vehicle category. The figure also illustrates the difference between the "high scenario" and the "low scenario". Given that more vehicles with ICE remain in the stock in the "low scenario", the GHG emissions are higher for this scenario. The GHG emissions correspond to the reduction potential through the conversion of ICE vehicles to locally emission-free drive technologies. In addition to the commercial vehicle categories, the passenger car category is also shown in this figure (more detail in section 8.2.1).

Figure 9: GHG reduction potential in 2040



Source: Umweltbundesamt

Greatest GHG reduction potential of commercial vehicles by HDV N3

In the "high scenario", the remaining HDV of category N3 with ICE emit more than 820 kilotonnes of CO_2 equivalents; in the "low scenario" this figure is more than 1.32 million tonnes of CO_2 equivalents. Among commercial vehicles, this vehicle category has the greatest GHG reduction potential through retrofitting, followed by the semi-trailers.

Reduction potential of 4.2 million tonnes of CO_2 equivalents through retrofitting

In total, the vehicle categories illustrated in Figure 9 result in a reduction potential of more than 4.2 million tonnes of CO_2 equivalents in the "high scenario". This corresponds to 21 % of the total emissions of the road transport sector in 2020 (UMWELTBUNDESAMT, 2022). In the "low scenario", the total reduction potential of all illustrated vehicle categories is around 7.2 million tonnes of CO_2 equivalents (corresponding to as high as 35 % of the total emissions of the road transport sector in 2022) (UMWELTBUNDESAMT, 2022).

5.3 Life cycle analysis of conversion solutions

Analysis of the direct and indirect GHG emissions

Apart from the GHG emissions caused by driving the vehicles (explained in section 5.2), the question of the climate compatibility of alternative fuels and drive systems such as electromobility will be answered not only in the transport sector, but also in the energy and industry sectors. In this context, life cycle assessments (or life cycle analyses, LCA) are prepared, which balance the upstream and downstream (or indirect) GHG emissions in addition to the direct GHG emissions from driving over the entire life cycle.

The basis for this chapter is the calculation method from the study published in 2022 by the Environment Agency Austria: "Life Cycle Assessment of Heavy-Duty Vehicles and Buses" (UMWELTBUNDESAMT, 2022-c). Separate LCAs were conducted for the retrofitting of an exemplary vehicle of the category N3, a semi-trailer and a public bus.

It was assumed that the exemplary vehicles were already 7 years old at the time of the retrofit and would be in service for another 7 years after the retrofit. Table 9 gives an overview of the specifications of the exemplary vehicles.

Table 9: Vehicle specifications

	HDV N3	**Semi-trailer**	**Public bus**
Vehicle type	3-axle solo truck, with box body	5-axle HDV in transit traffic, with tarpaulin body	Single-deck city bus, low-floor, 13 m
Gross vehicle weight	27 t	50 t	-
Average load	5 t	15 t	-
Capacity	-	-	100 persons
Average occupancy	-	-	30 persons
Annual mileage	66,900 km	76,900 km	42,000 km
Service life after retrofit	7 years	7 years	7 years

These input parameters were used to model the LCA. On the one hand, the induced GHG emissions of the converted vehicle with a further service life of 7 years were calculated. On the other hand, the saved GHG emissions in these 7 years resulting from the retrofit compared to the vehicle with ICE were calculated.

Calculation of induced GHG emissions of converted vehicle

GHG emissions related to vehicle production took into account those of the new components installed during retrofitting: the electric motor, the electric powertrain, the batteries and, if applicable, the fuel cell system and the hydrogen tank. GHG emissions for the production of the basic vehicle were not included since the vehicle already existed. Moreover, the induced GHG emissions included the indirect emissions from electricity generation or the indirect emissions from hydrogen production via electrolysis with renewable energies. The converted vehicle does not produce any direct GHG emissions during operation.

In the case of the N3 truck and the public bus, in order to take different locally emission-free drive technologies into account, the induced GHG emissions were averaged for the following 3 technologies:

- BEV with renewable energy mix and overnight charging;
- BEV with renewable energy mix and opportunistic charging;
- FCEV with hydrogen generated with renewable energies.

In the case of the semi-trailer, the induced GHG emissions were averaged for the following two technologies:

- FCEV with hydrogen generated with renewable energies;

- BEV with overhead line with renewable energy mix.

It should be emphasised here that energy supply is always based on renewable energy sources, including electrolysis for the production of hydrogen.

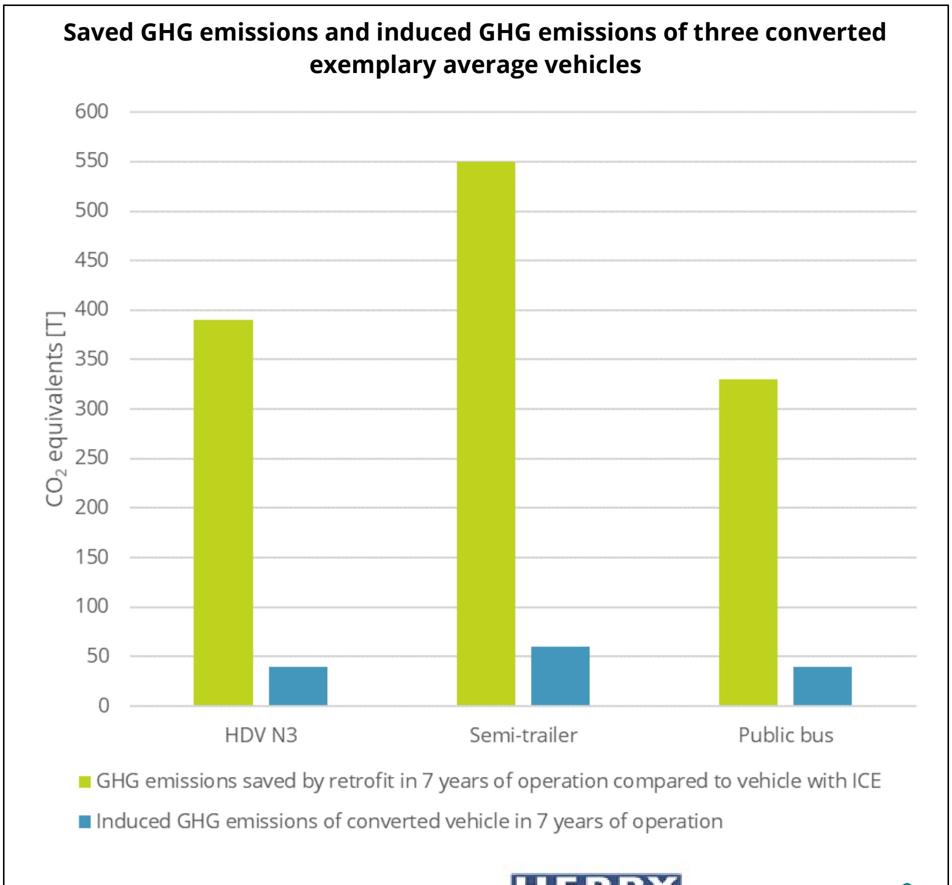
Calculation of GHG emissions saved by retrofitting

The GHG emissions saved by retrofitting were calculated based on the GHG emissions of the comparison vehicle with ICE during 7 years of operation. The GHG emissions of the ICE vehicle include the emissions caused by the production of urea solution ("AdBlue"), the direct emissions of fossil fuels and the indirect fossil fuel emissions.

GHG savings of 550 T CO_2eq through retrofitting a semi-trailer

Figure 10 shows the results of the LCA for the three converted exemplary average vehicles. By comparison with a similar vehicle with ICE, the HDV N3 saves 390 tonnes of CO_2 equivalents in 7 years of operation, the semi-trailer 550 tonnes of CO_2 equivalents and the public bus 330 tonnes of CO_2 equivalents. The induced GHG emissions in 7 years of operation for the HDV as well as for the public bus are 40 tonnes of CO_2 equivalents and for the semi-trailer 60 tonnes of CO_2 equivalents.

Figure 10: Saved GHG emissions and induced GHG emissions of converted vehicles



Source: Umweltbundesamt

It is important to note that the results strongly depend on the assumptions and specifications of the input parameters, in particular on:

- the age of the vehicle at the time of the retrofit;

- the useful life of the vehicle after the retrofit;
- the intensity of use of the converted vehicle (mileage).

However, it can be stated in any case that retrofitting a vehicle results in significant GHG savings.

6 COSTS FOR VEHICLE CONVERSIONS

The feedback on the questionnaire sent to the most relevant companies offering conversion technologies (result according to section 3.3) formed the basis for the estimation of the current and future conversion costs per vehicle. Accompanying desktop research on conversion costs and prices supplemented and validated the information from the conversion companies. This desktop research helped especially regarding current and actual battery costs.

Vehicle categories

It was necessary to restrict the cost analysis to selected vehicle categories and conversion technologies for a couple of reasons:

- The bus category M2 has a very small market share for commercial buses and only a rather small number of conventional M2 vehicle makes and models exist. Conversion companies only reported costs for M3 because M2 conversion is not particularly relevant;
- There is more or less no serial production of new FCEV. In addition, there are only a few companies offering conversion to FCEV and virtually no conversion kits are currently offered.

These are the reasons why the analyses of costs and prices as well as the TCO comparison were only performed for the following vehicle categories and only for the conversion from conventional vehicles to BEV:

- N1: Light goods vehicle up to 3.5 t gross vehicle weight;
- N2: Heavy goods vehicles from 3.5 to 12 t gross vehicle weight;
- N3: Heavy goods vehicles with more than 12 t gross vehicle weight;
- M3: Vehicles used for the carriage of passengers and comprising more than eight seats in addition to the driver's seat, with a maximum authorised mass exceeding 5 t.

6.1 Cost components and their (current and future) costs

As stated at the beginning of this chapter 6, a literature analysis and a questionnaire involving retrofit companies (together with personal online interviews with two of these companies) were the basis for the cost information. The following steps were taken to estimate current and future conversion costs for the different vehicles categories:

- Literature research (WIEN ENERGIE, 2021, HANDELSBLATT, 2021, STATISTA, 2023, TRANSPORT & ENVIRONMENT, 2020);
- Detailed questionnaire sent to 7 retrofit providers, 3 detailed responses;
- Two personal online interviews with retrofit providers;
- Comparison of findings and results;

- Discussion of differences and filling of gaps (in individual online meetings and email contact with retrofitters);
- Discussion of results with the project advisory board;
- Final evaluation of current and future costs per cost component.

The relevant cost components were identified in section 3.1. Due to the fact that the cost information from the literature and from the questionnaire involving retrofitters could not be gathered in such a detailed way, the costs are presented for the following aggregated cost components:

- Dismantling and assembly as well as chassis work conversion (personnel costs) + conversion;
- Battery;
- Electronic control (incl. charging system);
- Drive (engine; current transformer, gearbox, axle);
- Other components (auxiliary units);
- Overhead costs + profit margin.

The battery costs (measured in EUR / kWh) presented by the retrofit companies were rather high compared to the costs presented in different sources identified during the desktop research. The discussion on this within the project team, with the retrofit companies and with the advisory board resulted in the finding that retrofitters have higher battery costs than OEMs (producing new BEV) mainly due to the lower number of batteries, causing high costs per battery. This difference will be reduced in future (due to a higher number of vehicles retrofitted) but will not disappear.

The battery costs included in the figures below are based on these differentiated battery costs per kWh and a selected battery capacity per vehicle category based on new reference vehicles offered (see section 6.2 below).

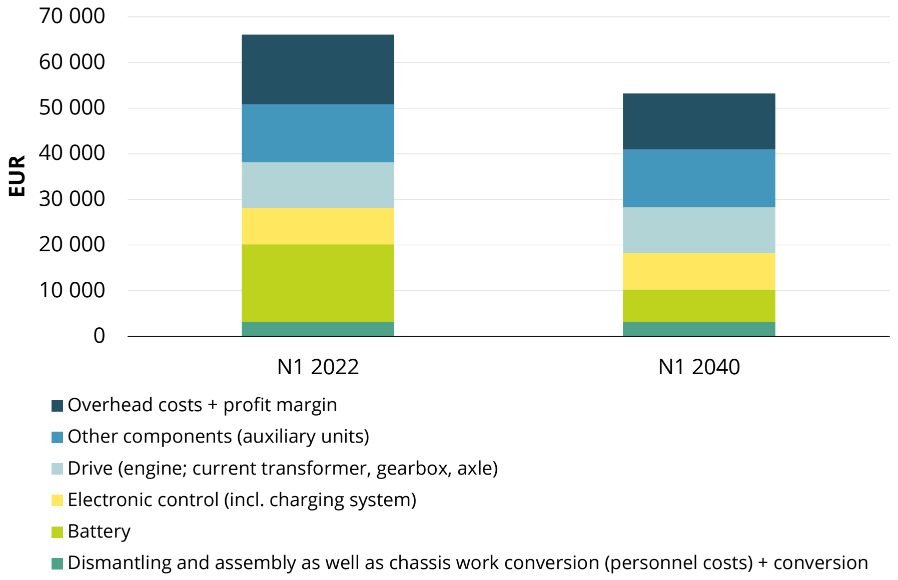
Future costs are shown at 2022 prices. The current situation with volatile market prices especially in the electronics sector makes estimations for future costs difficult and uncertain. Nevertheless, both expectations from retrofit companies and information found in the literature indicate that

- costs are currently increasing in many areas due to supply chain problems and general price rises;
- in the long term, this should level out again and the increases that have occurred will be offset by higher unit numbers;
- only battery costs are expected to decrease in the long term.

The following figures show average retrofit costs per conversion component for the conversion of one vehicle. These costs are achievable only when the retrofit is performed with companies offering conversion kits.

Figure 11: Retrofit costs per conversion component for N1 in 2022 and 2040

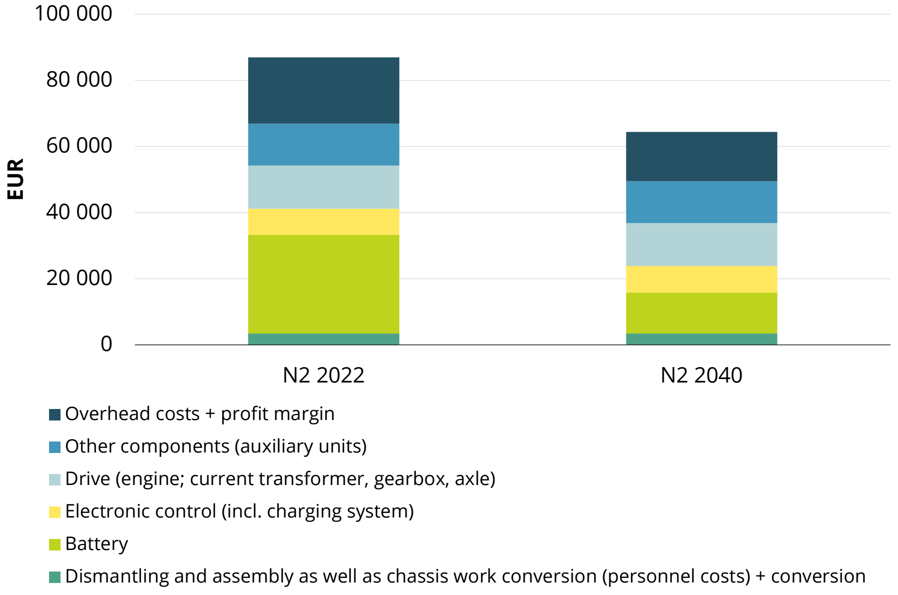
Retrofit costs per conversion component for N1 in 2022 and 2040



Source: own estimation based on literature and questionnaire involving retrofit companies

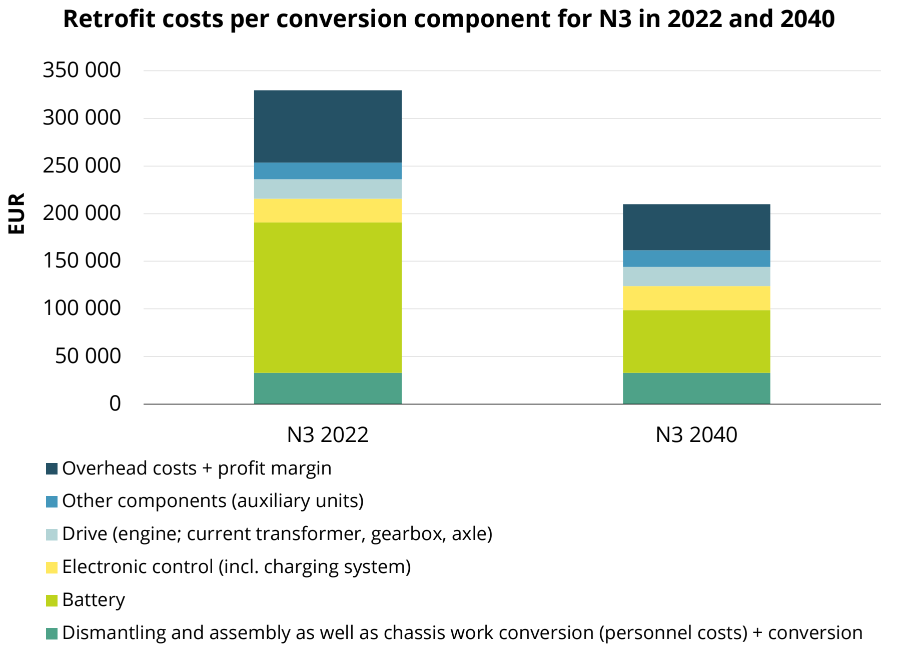
Figure 12: Retrofit costs per conversion component for N2 in 2022 and 2040

Retrofit costs per conversion component for N2 in 2022 and 2040



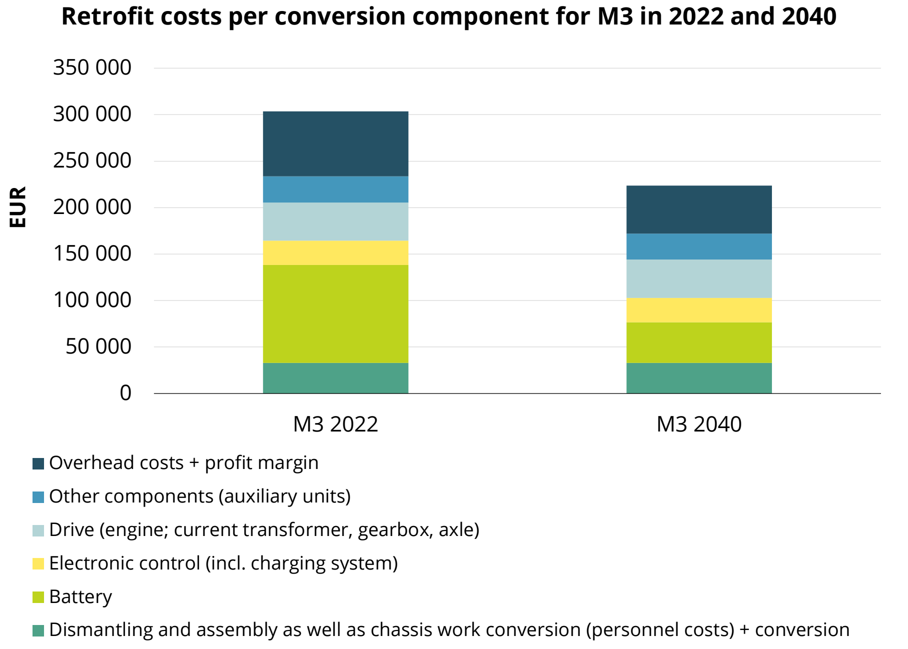
Source: own estimation based on literature and questionnaire involving retrofit companies

Figure 13: Retrofit costs per conversion component for N3 in 2022 and 2040



Source: own estimation based on literature and questionnaire involving retrofit companies

Figure 14: Retrofit costs per conversion component for M3 in 2022 and 2040



Source: own estimation based on literature and questionnaire involving retrofit companies

6.2 TCO comparison

In order to compare the costs for the use of new commercial e-vehicles with the costs of converted commercial vehicles, the total costs during the period of ownership of the vehicle were compared with each other. In addition, the costs incurred for the use of a conventional commercial vehicle during the period of ownership were also included in the comparison. Comparative TCO[1] calculations were carried out for this purpose.

For the comparison, it is relevant to consider current and future subsidies for the purchase of climate-neutral vehicles or for the conversion to climate-neutral vehicles. In Austria, EBIN is a subsidy for the purchase of new emission-free buses (M2 and M3) and the charging infrastructure. A subsidy for the conversion of buses is not provided. The subsidy for the purchase of emission-free commercial vehicles (N1, N2 and N3) and charging infrastructure (ENIN) is currently being developed. This support programme will probably also promote the retrofitting of existing vehicles (information from the responsible ministry (BMK)). The subsidy rates are (will be) as follows:

- EBIN
  - 80 % of the difference in acquisition costs between comparable internal combustion vehicles (ICV) and BEV (and FCEV);
  - No subsidy for conversion.
- ENIN
  - 80 % of the difference in acquisition costs between comparable ICV and BEV;
  - 80 % of the conversion costs for conversion from ICV to BEV.

In the discussion with the advisory board, it was stated that these subsidies will in any case be phased out by 2040 as no new registrations of conventional vehicles will be permitted by 2040.

TCO calculations were therefore performed for the following variants:

Table 10: Variants for TCO comparison

N1, N2, N3	• Conventional vehicle in 2022 • New BEV in 2022 without ENIN • New BEV in 2022 with ENIN • Existing vehicle converted to BEV in 2022 without ENIN • Existing vehicle converted to BEV in 2022 with ENIN • New BEV in 2040 without ENIN • Existing vehicle converted to BEV in 2040 without ENIN

[1] TCO: Total Cost of Ownership

M3	• Conventional vehicle in 2022 • New BEV in 2022 without EBIN • New BEV in 2022 with EBIN • Existing vehicle converted to BEV in 2022 without EBIN • New BEV in 2040 without EBIN • Existing vehicle converted to BEV in 2040 without EBIN

In order to implement comparable TCO calculations, a number of assumptions and specifications have to be made and comparable reference vehicles (conventional and BEV, as well as conventional vehicles to be converted to BEV and characteristics of the converted BEV) must be defined for each vehicle category. Vehicles currently on the market in the classes N1, N2, N3 and M3, which have comparable characteristics (for ICE and BEV within the categories) with regard to performance, max. total weight, max. number of persons to be transported and dimensions), were researched and suitable reference vehicles were defined for this purpose.

- Reference vehicles for N1:
  - ICV (which is being converted): MB SPRINTER Standard, panel van, high roof, 311 CDI, 6-speed manual transmission, front-wheel drive, 84 kW, 3.5 t gross vehicle weight;
  - BEV: eSPRINTER Standard, panel van, high roof, front-wheel drive, 85 kW, 3.5 t gross vehicle weight.
- Reference vehicles for N2:
  - ICV (which is being converted): Mitsubishi Canter 7C15, flatbed, 110 kW, 7.5 t gross vehicle weight;
  - BEV: Mitsubishi eCanter 7C18e, flatbed, 115 kW, 7.45 t gross vehicle weight.
- Reference vehicles for N3:
  - ICV (which is being converted): MB Actros S/M cab, 2545 L 6x2, platform chassis, 330 kW, 26 t gross vehicle weight;
  - BEV: MB eActros e400 L 6x2, platform chassis, 330 kW, 27 t gross vehicle weight.
- Reference vehicles for M3:
  - ICV (which is being converted): MB Citaro 2 doors, 220 kW, 19.5 t gross vehicle weight, 31 seats, 75 standing places;
  - BEV: MB eCITARO 2 doors, 125 kW, 20 t gross vehicle weight, 29 seats, 56 standing places.

The following additional specifications were developed for the TCO calculation:

- Holding period of new vehicles: 7 years;
- Age of the vehicles to be retrofitted: 7 years;
- Holding period of the retrofitted vehicles: 7 years;

- Average daily kilometres:
  - N1: 145 km;
  - N2: 150 km;
  - N3: 400 km;
  - M3: 100 km;
- Interest rate for the acquisition costs (financing costs): 4 %;
- Fuel consumption and CO_2 emissions according to OEM data;
- Taxes and tolls according to current regulations in 2022;
- Fuel price on 10 October 2022 (fuel price monitor);
- Electricity prices on 14 October 2022;
- Electricity mix used:
  - 80 % commercial electricity (charging at depot, construction of charging points included in electricity costs);
  - 20 % charging at public charging points (source for price: ÖAMTC AC up to 75 kWh);
- Constant costs/prices for the components except for battery:
  - No estimations regarding changes in energy and fuel prices, prices for purchase, taxes, etc. in order to focus on comparison between BEV and converted vehicles only;
  - No expected changes for conversion components except for battery (see section 6.1).

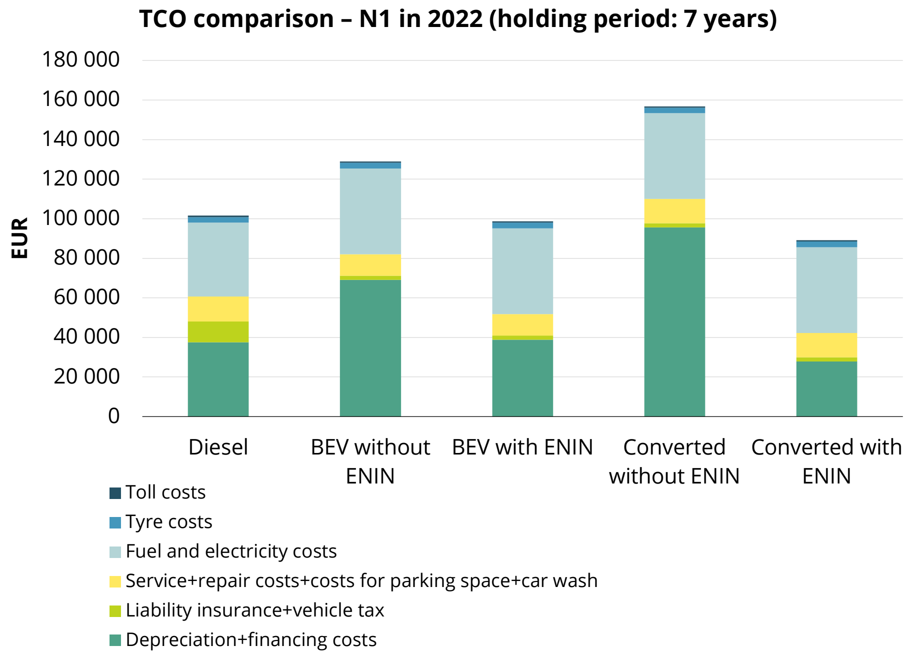
The following cost blocks were considered for determination of the TCO:

- Depreciation of acquisition costs / conversion costs:
  - New price plus registration tax (*Normverbrauchsabgabe*), if relevant, minus residual value minus subsidy (+conversion costs);
  - Depreciation period = holding period;
- Financing costs (acquisition costs or conversion costs);
- Liability insurance;
- Vehicle tax or engine-related insurance tax;
- Costs for parking space, car wash and similar;
- Service and repair costs;
- Tyre costs (depending on the number of tyres, the mileage of the tyres and the average mileage per vehicle and year);
- Fuel and electricity costs;
- Toll costs (on motorways).

The following figures show the comparative results of the TCO calculations for the vehicle classes examined (N1, N2, N3, M3) for 2020 and 2040.

It should be emphasised once again at this point that the results of TCO model calculations depend very heavily on the assumed average annual mileage and the assumed holding period. These two components influence the fixed and the km-dependent costs and their share of the total costs. The higher the average annual mileage, the higher the influence of the km-dependent costs (especially fuel and energy costs as well as toll costs). In addition, it should be noted that the costs for 2040 were kept constant with regard to most cost blocks (insurance, taxes and duties, fuel and energy costs, toll costs, but also acquisition costs except for battery costs) in order not to distort the comparison between new BEV and retrofitted vehicles. Based on the analysis of the conversion costs, only the battery costs were changed, not the costs for the other conversion components (for reasons, see section 6.1).

Figure 15: TCO comparison – N1 in 2022



Source: own calculation based on own specifications, desk research and questionnaire involving retrofit companies

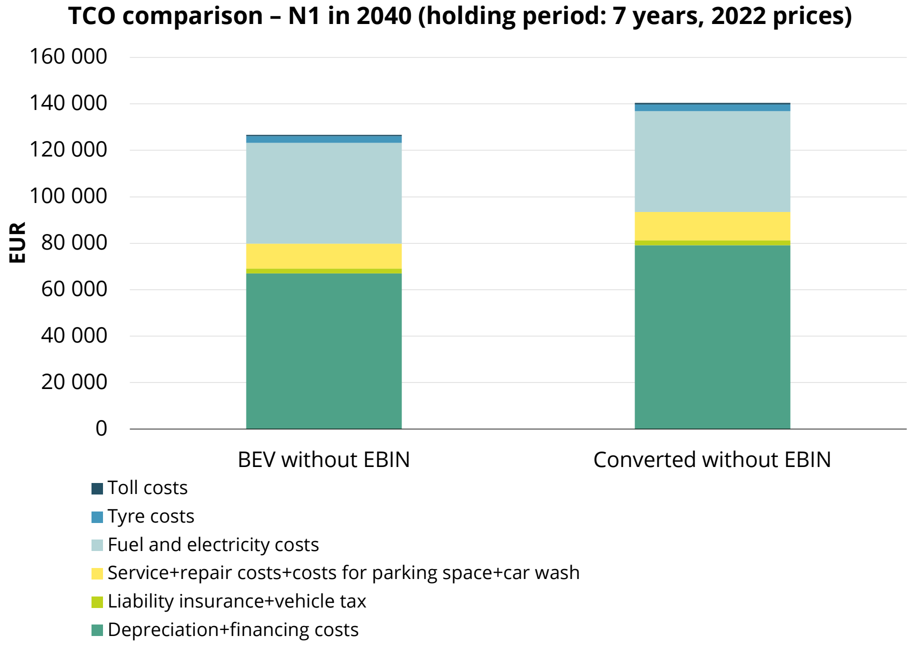
Under the framework conditions outlined, but without ENIN funding, the TCO for both (newly purchased N1 BEV and N1 diesel vehicles converted to BEV) is significantly higher than for conventional newly purchased N1 diesel vehicles.

Subsidies have an influence on the cost comparison. Without ENIN subsidies (for new purchase and conversion), the purchase of a new N1 BEV is more favourable than the conversion of existing N1 diesel vehicles under the outlined framework conditions. However, with the planned ENIN, the conversion of existing vehicles is more favourable than the purchase of new BEV in the case of N1. This is mainly due to:

- the ratio between the purchase costs of the N1 BEV and N1 diesel vehicle, which has a comparatively low factor of 1.9. This leads to a comparably low ENIN subsidy for new BEV in absolute terms; and
- the ratio of conversion costs and purchase costs for new BEV. Both costs are almost the same for N1.

Both ratios result in a comparatively higher absolute subsidy for retrofitting.

Figure 16: TCO comparison – N1 in 2040

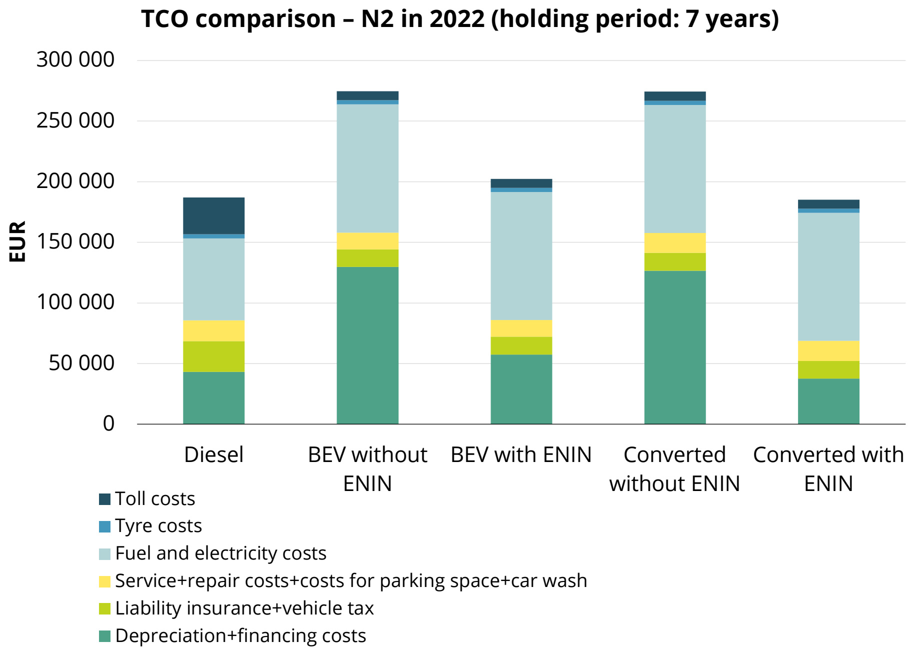


Source: own calculation based on own specifications, desk research and questionnaire involving retrofit companies

As mentioned at the beginning of this chapter, the TCO comparison for the year 2040 was only carried out without ENIN subsidies and not at all for conventional diesel vehicles.

For N1 vehicles, the cost for the purchase of new BEV in 2040 will be approx. 7 % lower than the cost for the conversion of existing diesel vehicles to BEV (under the described framework conditions).

Figure 17: TCO comparison – N2 in 2022

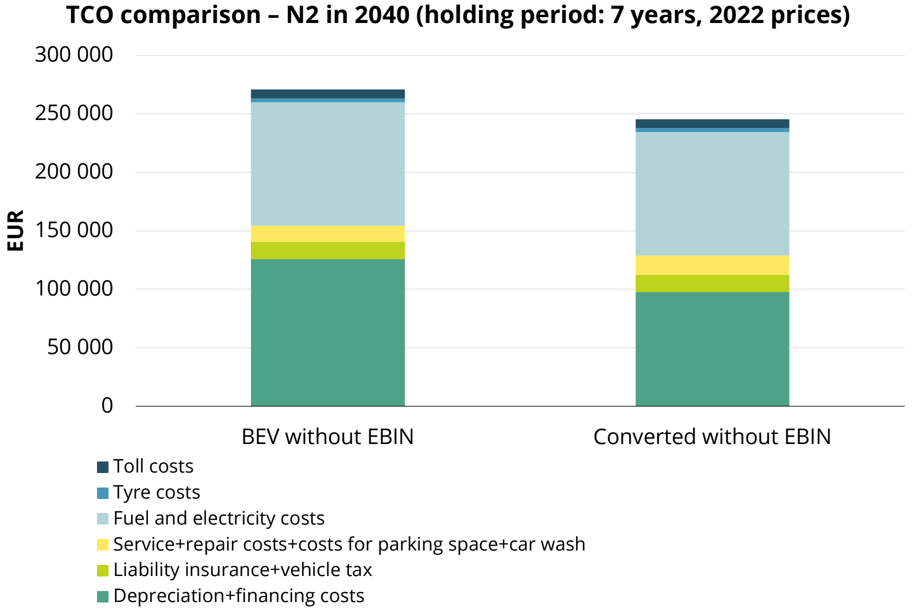


Source: own calculation based on own specifications, desk research and questionnaire involving retrofit companies

For N2 vehicles, when taking the planned ENIN subsidy into consideration, the lowest TCO results for existing retrofitted vehicles in 2022. Newly purchased N2 BEV have a higher TCO than conventional diesel vehicles despite the ENIN subsidy.

Also, without ENIN support, the converted vehicles have a lower TCO compared to newly purchased BEV. In this case, the TCO for both climate-neutral variants is significantly higher than for a newly purchased conventional N2 diesel vehicle.

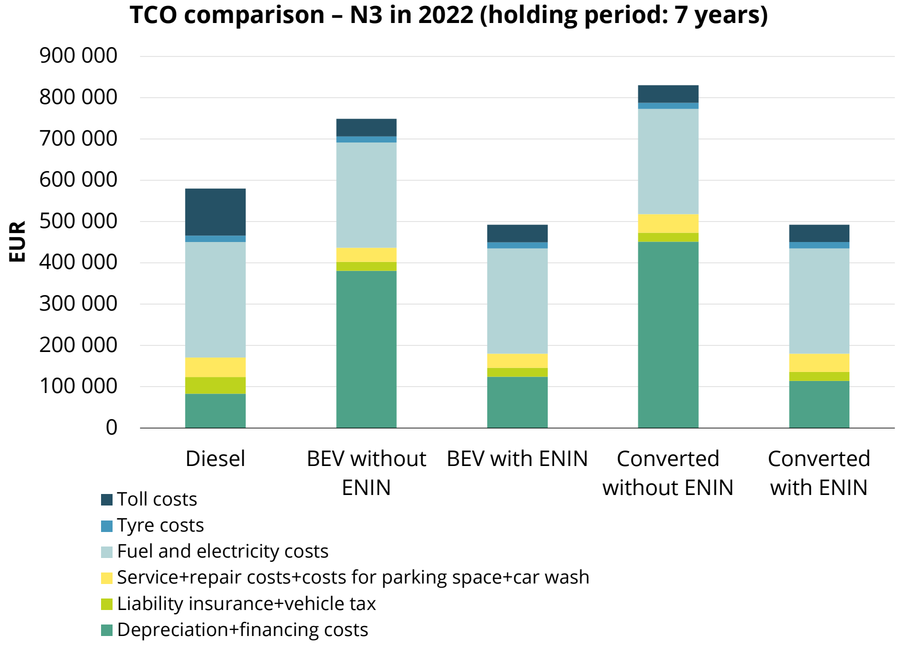
Figure 18: TCO comparison – N2 in 2040



Source: own calculation based on own specifications, desk research and questionnaire involving retrofit companies

In 2040 (again only the two climate-neutral variants without subsidies were compared), the TCO for existing retrofitted vehicles will be approx. 12 % lower than for newly purchased BEV (under the selected conditions).

Figure 19: TCO comparison – N3 in 2022



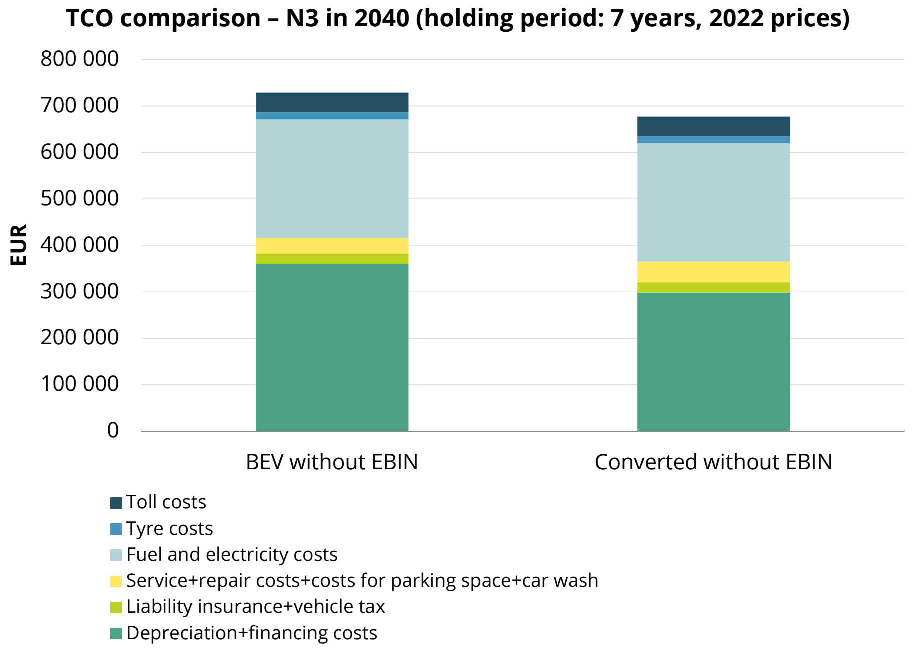
Source: own calculation based on own specifications, desk research and questionnaire involving retrofit companies

The TCO comparison for N3 in 2022 results in the same ranking as for N2. However, the differences between the compared variants are higher.

Without ENIN funding, the two climate-neutral variants have a significantly higher TCO than the use of conventional diesel vehicles. With ENIN funding, the TCO of the climate-neutral variants can be reduced significantly and is then lower than the TCO when using conventional diesel vehicles.

Both with and without ENIN support, the TCO for the use of existing retrofitted vehicles is lower than for the use of new BEV.

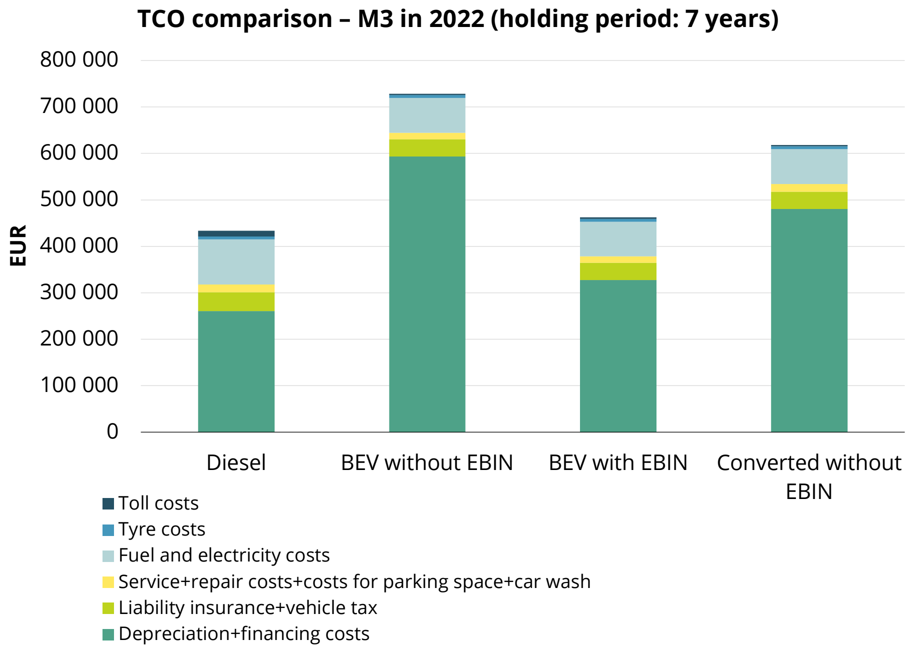
Figure 20: TCO comparison – N3 in 2040



Source: own calculation based on own specifications, desk research and questionnaire involving retrofit companies

In 2040 (again only the two climate-neutral variants without subsidies were compared), the TCO for existing retrofitted vehicles is approx. 14 % lower than for newly purchased BEV under the selected conditions.

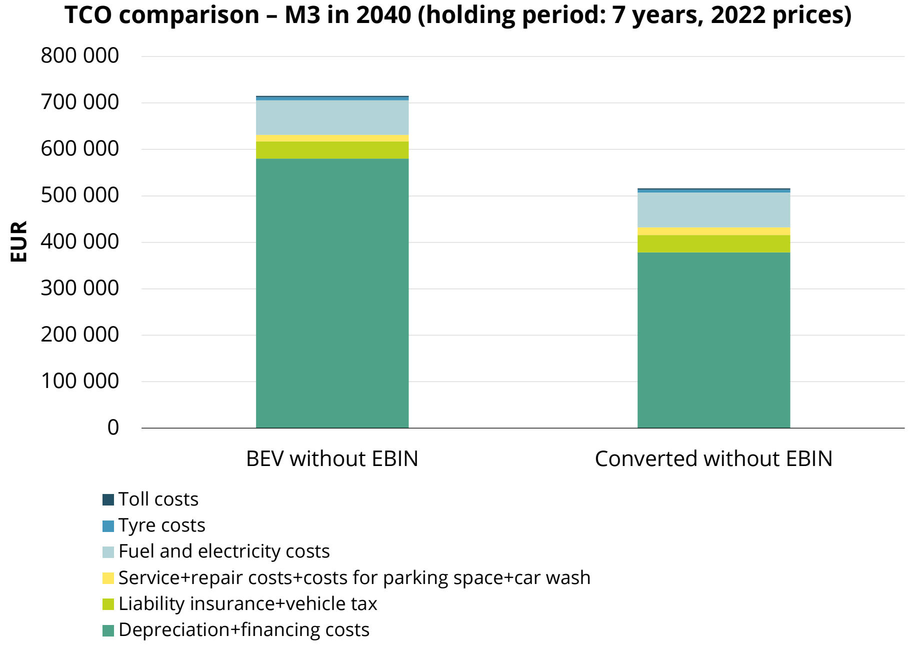
Figure 21: TCO comparison – M3 in 2022



Source: own calculation based on own specifications, desk research and questionnaire involving retrofit companies

The results for buses (M3) for 2022 are different from those for commercial vehicles N2 and N3. Since the existing EBIN subsidy does not provide for the retrofitting of existing vehicles, this variant is not shown. Under the assumed general conditions, new M3 BEV have a higher TCO than new conventional diesel vehicles, both with and without EBIN funding. Without EBIN support, the TCO of BEV is almost 70 % higher compared to conventional diesel vehicles. In contrast, the difference in TCO for existing retrofitted buses compared to new conventional diesel vehicles is comparatively low at 18 %. This is due to the high acquisition costs for new BEV buses (source: information from a bus OEM). These acquisition costs are significantly higher than the acquisition costs for N3 trucks and significantly higher than the conversion costs for M3 buses.

Figure 22: TCO comparison – M3 in 2040



Source: own calculation based on own specifications, desk research and questionnaire involving retrofit companies

Due to the comparatively high acquisition costs for BEV buses (as already stated for 2022), the TCO for retrofitted buses in 2040 will be significantly lower than the TCO for newly acquired BEV. This ratio will only change if the high acquisition costs for buses can be reduced. In any case, the future reductions in battery costs assumed in this study are not sufficient.

It should be noted, however, that it was not possible to obtain concrete current purchase costs for diesel and electric buses from manufacturers or dealers. Even after contact in person, no concrete values, only approximate from-to figures, were given for both conventional diesel buses and BEV buses. Concrete prices are only communicated to tendering bodies in the case of corresponding tenders.

7 ECONOMIC POTENTIAL FOR AUSTRIA

Effects of vehicle conversions on the Austrian economy

Vehicle conversions generate **economic activity** in Austria when conversion components are produced in the country and when the conversions themselves are carried out by Austrian companies. Both activities will require the availability of a **skilled workforce** to complete these tasks by the year 2040. It is therefore important for policymakers not only to understand the potential of vehicle conversions for the Austrian economy in terms of **value added**, but also to be aware of the demand for trained workers in the various sectors that vehicle conversions involve.

Comparison with the EMAPP2 study

The *E-Mapp 2* study, conducted by the Austrian Fraunhofer Institute et al., found **positive effects** on Austrian value added and employment resulting from a shift towards electric mobility for passenger cars between 2020 and 2030 (FRAUNHOFER AUSTRIA RESEARCH GMBH et al., 2020). The results of the projection show annual growth rates for value added and employment in the passenger car industry of 1.7 % and 1.9 %, respectively. In absolute numbers, Austrian value added in the passenger car industry is predicted to increase by EUR 500 million in total over the period, while employment in that industry is predicted to rise by about 7,000 people.

The ConVErT project sought to **provide similar figures for retrofitting** all remaining ICE-driven commercial vehicles with electric drives by 2040. In contrast to the above-mentioned *E-Mapp 2* study, however, which focuses on the direct economic effects on the Austrian passenger car industry alone (FRAUNHOFER AUSTRIA RESEARCH GMBH et al., 2020) – a narrow segment of the economy – **ConVErT estimated the total economic effects** of vehicle conversions on all economic sectors, including the upstream and downstream sectors linked to those producing and installing the retrofit solutions. This was made possible by using an extended input-output model of the Austrian economy, the Environment Agency Austria's MIO-ES model.

EAA's MIO-ES model

MIO-ES is a macroeconomic input-output model with integrated energy system for Austria (UMWELTBUNDESAMT, 2023). It was applied in the ConVErT project to **quantify the potential effects of vehicle conversions on Austrian value added and employment**. As the model fully integrates the Austrian energy system in physical units, its results include not only feedback effects within the economic system but also between the economic system and the energy system. The current version of the model is based on data from Statistik Austria (input-output statistics, energy balances, national accounts and household budget survey) as well as from Eurostat (EU Statistics on Income and Living Conditions). It is calibrated to the base year 2014 and provides annual results up to 2050.

The model's key feature that makes it suitable for quantifying the total economic effects of vehicle conversions on the Austrian economy is its **input-output core**, which reflects the integration of all economic sectors as suppliers of inputs for the production of output in other sectors. Therefore, the model's results cover not only the **direct effects** of increased economic demand in those sectors that are affected directly by vehicle conversions, but also the **indirect**

effects in related, supplying sectors as well as the **induced effects** of increased overall economic activity via higher earnings and consumption.

7.1 The economic impulse resulting from vehicle conversions

Expenditures for vehicle retrofitting increase economic demand

As a first step, the impulse to economic demand in Austria generated by commercial vehicle conversions was calculated. This impulse stems from the expenditures necessary for retrofitting all remaining commercial vehicles containing ICE drives with zero-emission drives by 2040. These expenditures represent investment expenditures that translate into increased final demand for the production of conversion components and for the retrofitting services of motor vehicle repair shops and retrofitting companies in Austria. Therefore, in section 7.2 below, the total conversion expenditures derived in this section are mapped to the relevant goods and services categories in MIO-ES, before their effects on value added and employment are simulated and the results presented in section 7.3.

To calculate **total conversion expenditures**, we combined the following two data sets developed in earlier work packages of the project:

- Average retrofit costs per conversion component and vehicle category in 2040, at 2022 prices (see Figure 11 to Figure 14 in section 6.1);
- The number of remaining commercial vehicles with ICE in 2040 by vehicle category for the "high scenario", which is consistent with Austria's 2030 Mobility Master Plan in terms of new registrations of zero-emission vehicles (see Table 6 in section 5.1.2).

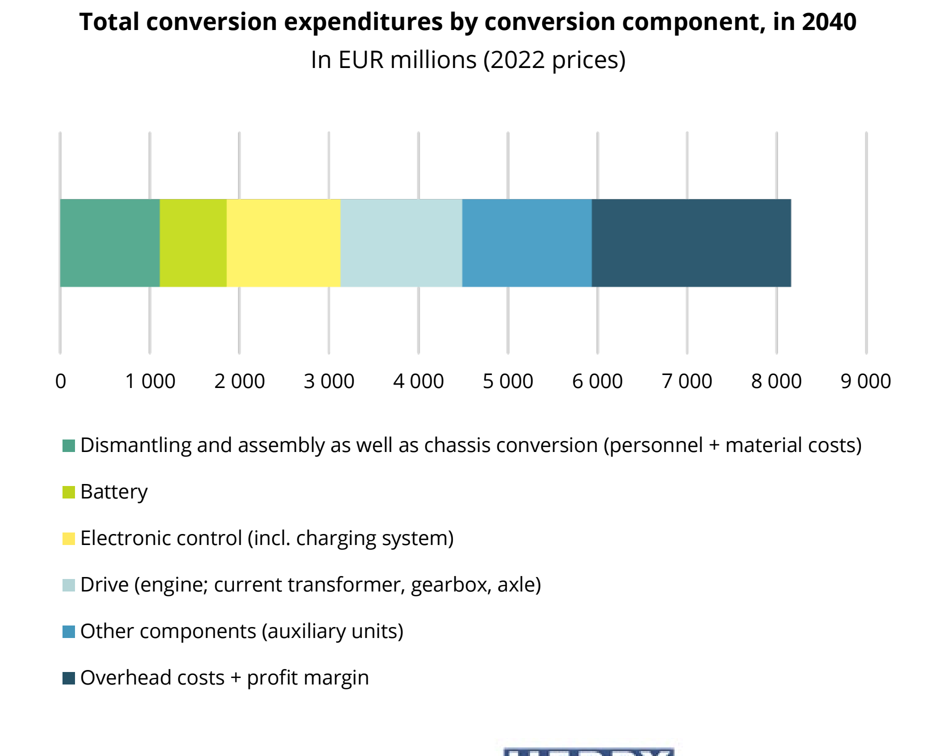
Multiplying average retrofit costs per conversion component and vehicle category by the number of remaining vehicles per category yields total conversion expenditures per conversion component. These are shown in Figure 23 below (at 2022 prices).

Total expenditures for vehicle conversions amount to 1.3 % of 2040 GDP

The total expenditures necessary to convert all remaining ICE-driven commercial vehicles to zero-emission drives by 2040 amount to just over **EUR 8 billion**. This represents 1.3 % of Austria's GDP in 2040 at 2022 prices, as projected by the MIO-ES model.

Figure 23 illustrates that the largest share of the total conversion expenditures concerns the activities of companies providing **retrofitting services**. This includes not only the dismantling, assembly and chassis conversion work but also the overhead costs and profit margins. The remaining share of the total conversion expenditures consists of the **internal vehicle parts** that need to be exchanged, namely the drive, electronic control and charging system, auxiliary components such as heating/cooling units, and to a lesser extent the battery.[2]

Figure 23: Total commercial vehicle conversion expenditures by conversion component, in 2040, in EUR millions (2022 prices)



Source: Umweltbundesamt

Total savings from vehicle conversions amount to 0.3 % of 2040 GDP

The TCO comparison in section 6.2 also provides numbers for the **total savings** that can be made from the conversion of an ICE-driven commercial vehicle in 2040 compared to replacing it with a new battery electric vehicle. The TCO comparison indicates that for all categories except for N1 in 2040, it is cheaper to convert the vehicle than to buy a new BEV.

If all remaining ICE-driven vehicles in the categories except for N1 are converted by 2040, i.e. categories N2 to M3, then the total savings in comparison to buying a new BEV are **EUR 1.83 billion** (at 2022 prices) or 0.3 % of 2040 GDP.

These figures were obtained by multiplying the following values:

- The difference in TCO between buying a new BEV and retrofitting an ICE-driven vehicle in 2040, at 2022 prices, for the vehicle categories N2 to M3 (see Figure 18, Figure 20 and Figure 22 in section 6.2);

[2] Since it is highly uncertain from today's perspective whether batteries for commercial electric vehicles will be produced in Austria by 2040, only 30 % of the total expenditure on this component was included in the analysis. This is in line with *E-Mapp 2*, which sees niche potential for the country in producing battery parts (FRAUNHOFER AUSTRIA RESEARCH GMBH et al., 2020).

- The number of remaining commercial vehicles with ICE in 2040 in the vehicle categories N2 to M3 for the scenario "high" (see Table 6 in section 5.1.2).

The savings accrue to the vehicle owners, who can spend them on other goods and services. Although this can be thought of as an additional stimulus to the economy, these savings are not included in the simulation of the economic potential of vehicle retrofitting for Austria in section 7.3. The reason for this is that the reference scenario for the savings differs from that used in the model simulations. In the latter, the reference scenario is one without conversions (status quo). The savings, on the other hand, were calculated in section 6.2 as a comparison with the purchase of a new BEV. Hence, deriving their economic effects requires the comparison of a conversion scenario with a BEV scenario, which is beyond the scope of this project.

7.2 Mapping the economic impulse to goods and services

In the next step, the total conversion expenditures identified in the previous section were allocated to those categories of goods and services in MIO-ES for which they generate additional demand. This was done by mapping the conversion components depicted in Figure 23 to the relevant categories of the EU's *Statistical Classification of Products by Activity* (CPA) employed in MIO-ES. CPA covers all goods and services produced in an economy and is closely related to the NACE classification[3] of economic sectors – also employed in MIO-ES – in that the production of each CPA product occurs in a single NACE sector.

To identify the relevant CPA categories for each conversion component, the classification documentation for CPA and NACE (EUROSTAT, 2008) as well as *E-Mapp 2* (FRAUNHOFER AUSTRIA RESEARCH GMBH et al., 2020) were consulted. EAA experts validated the final mapping, which is shown in Table 11 below.

Table 11: Mapping of conversion components to goods and services according to the CPA classification*

Conversion component	CPA category
Dismantling and assembly as well as chassis conversion (personnel + material costs)	45 Repair services, wholesale & retail trade of motor vehicles & motorcycles 25 Fabricated metal products
Battery	27 Electrical equipment

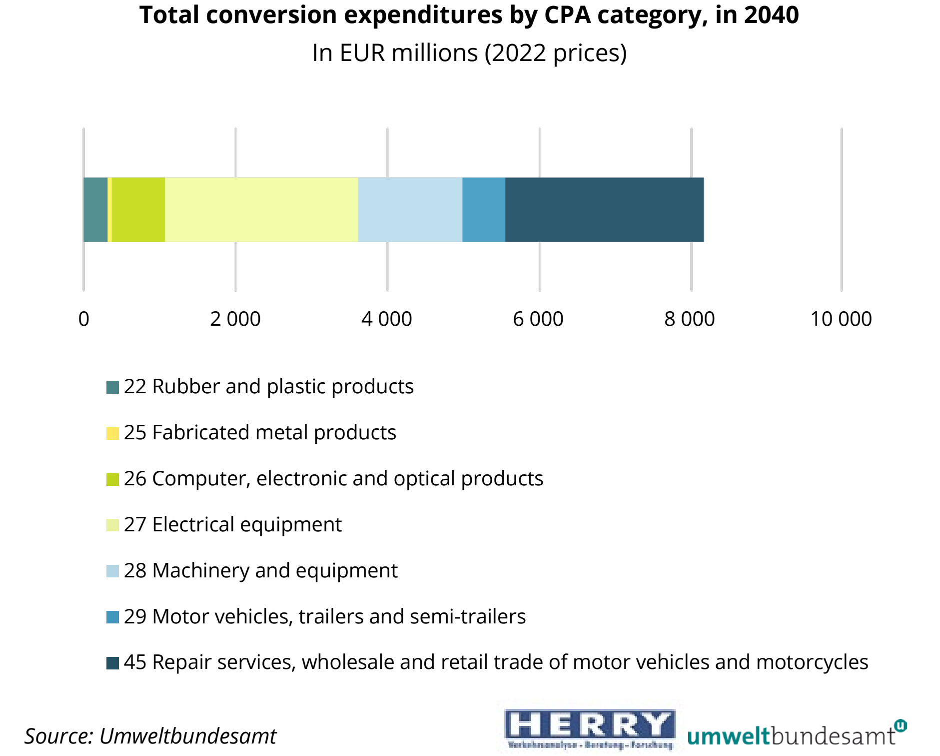
[3] NACE is the *Statistical Classification of Economic Activities in the EU*. The online CPA classification is available at https://ec.europa.eu/eurostat/documents/1995700/1995914/CPA-2008-structure-EN.pdf/bed6a577-75ac-4691-a312-6662311a9173.

Electronic control incl. charging system	26 Computer, electronic and optical products 27 Electrical equipment
Drive (engine; current transformer, gearbox, axle)	27 Electrical equipment 29 Motor vehicles, trailers and semi-trailers
Other components (auxiliary components, e.g. heating/cooling)	28 Machinery and equipment
Overhead costs + profit margin	45 Repair services, wholesale & retail trade of motor vehicles & motorcycles

* *CPA is the EU's Statistical Classification of Products by Activity employed in MIO-ES. "Products" covers both goods and services.*

Figure 24 illustrates the allocation of total conversion expenditures to the CPA categories. Roughly 30 % of total expenditure flows towards repair services in category 45 as well as electrical equipment in category 27. 17 % flows towards machinery and equipment (category 28), 9 % towards computers, electronic and optical products (26), 7 % towards components for motor vehicles (29), 4 % towards rubber and plastic products (22) and 1 % towards fabricated metal products (25).

Figure 24: Total commercial vehicle retrofit expenditures by CPA category, in 2040, in EUR millions (2022 prices)



The following assumptions apply to the economic analysis in the next section:

- By 2040, the retrofitting services in CPA category 45 will be carried out entirely by Austrian companies and repair shops. Since, at the time of writing, only a handful of providers of conversion services exist in Austria (see section 3.3), this will require further domestic development of this activity in the country by 2040;

- The other components in categories 26 to 29 may partly be imported, so that share of the total conversion expenditure will flow abroad and will not generate economic demand in Austria. This reflects the integration of Austrian production activities into global value chains. The remaining domestic demand impulse from the total expenditure on each component was calculated using sector-specific import shares from Statistik Austria's input-output statistics, which are integrated in MIO-ES.[4]

7.3 Simulation results for the macroeconomic effects of vehicle conversions

Finally, the effects of the impulse to final domestic demand generated by the conversion expenditures on Austrian value added and employment were simulated with the MIO-ES model. For this purpose, the total conversion expenditures by component, assigned to categories of goods and services as described in section 7.2, were inserted into the economic part of the model as an investment demand shock. To compute the effects of this impulse on value added and employment, the scenario with conversions was compared to a scenario without conversions (status quo or reference scenario). These effects illustrate the economic potential of vehicle conversions for the Austrian economy by 2040.

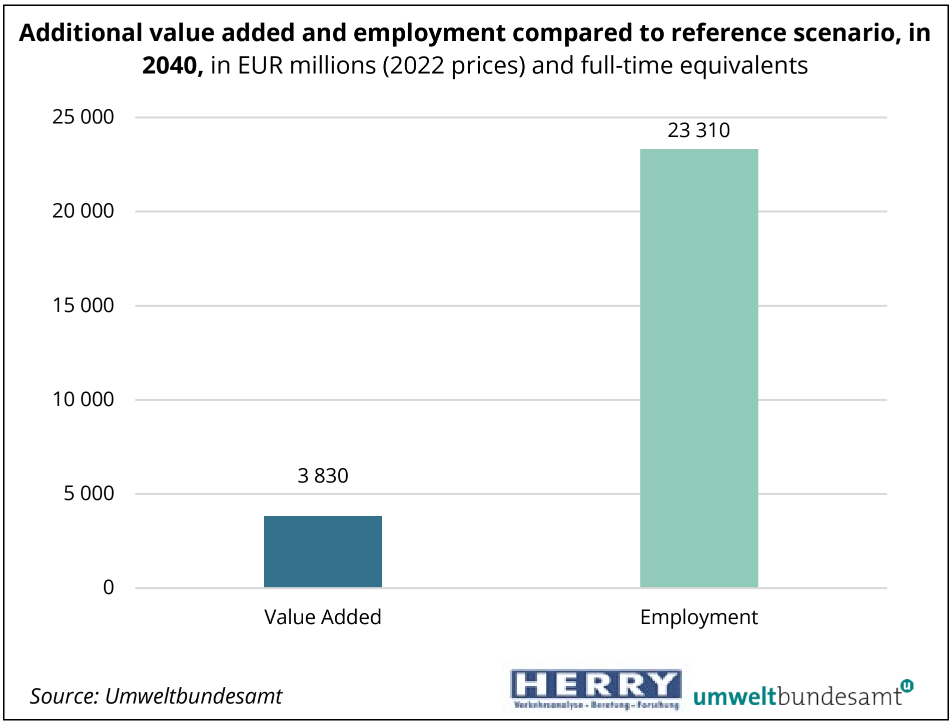
Additional value added of EUR 3.8 billion

As Figure 25 shows, vehicle conversion leads to substantial gains in value creation for the Austrian economy. Value added increases by EUR 3.8 billion or 0.7 % compared to the reference scenario without conversions. To gauge the size of this effect, it is helpful to relate this increase in value added to the original impulse to final domestic demand that the simulation results rest upon, i.e. the demand impulse that remains in the Austrian economy from the total conversion expenditures in Figure 23 and Figure 24 after accounting for the share that flows abroad via imports. This domestic value added multiplier equals 0.7[5], which is in line with the value of this multiplier from Statistik Austria's most recent input-output tables (STATISTIK AUSTRIA, 2021).

[4] These differ across activities. For example, 98 % of goods in category 29 (motor vehicles) are imported, compared to 85 % in category 26 (computers, electronic and optical products), 37 % in category 27 (electrical equipment) and 26 % in category 25 (fabricated metal products).

[5] A multiplier value of 0.7 implies that for every EUR 1 million of additional final domestic demand – in our case, total investment expenditure on vehicle conversions minus import shares – EUR 700,000 in value added is generated in the Austrian economy.

Figure 25: Additional value added and employment in conversion scenario compared to reference scenario (=no conversion)



Job potential of 23,000 full-time equivalents

Figure 25 also indicates that the additional employment generated from the expenditures on vehicle conversions is close to 23,300 full-time equivalents, which corresponds to an increase of 0.5 % compared to the reference scenario without conversions. Once again, the domestic employment multiplier can help judge the size of this effect. For every EUR 1 million of additional final domestic demand (total investment expenditures on vehicle conversions minus import shares), the results imply that 5 additional jobs are created on average in Austria. This value differs across economic sectors according to their employment intensity and is in line with the corresponding average multiplier from Statistik Austria (STATISTIK AUSTRIA, 2021).

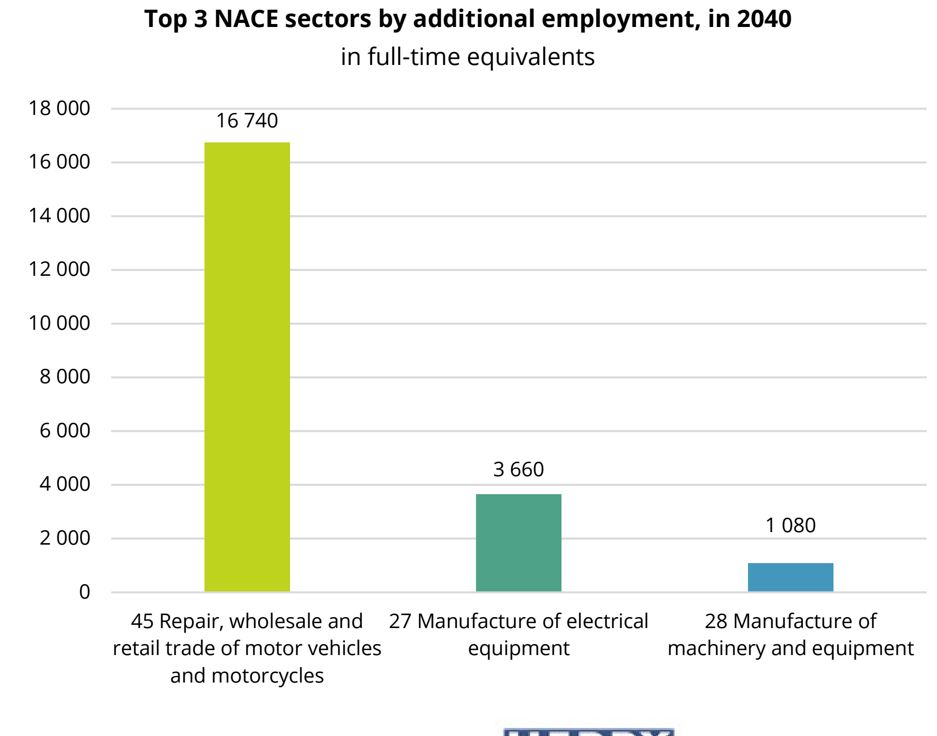
72 % of additional jobs generated in motor vehicle repair sector

To understand in which sectors the demand for additional workers is stimulated most by the vehicle conversions, Figure 26 indicates the top three sectors (according to the NACE classification) that account for at least 90 % of the total additional employment shown in Figure 25.

The main job gains (72 %) occur in the sector where the retrofits are carried out, namely NACE sector 45 (repair, wholesale and retail trade of motor vehicles and motorcycles). Compared to the reference scenario, employment in this sector increases by 13.4 %. Demand for additional work also stems from the following NACE sectors to a lesser extent:

- 27 (manufacture of electrical equipment), where employment rises by 5.5 %; and
- 28 (manufacture of machinery and equipment) (+0.8 %).

Figure 26: Top 3 NACE sectors with highest additional employment



Source: Umweltbundesamt

The repair sector is labour-intensive

If Figure 26 is compared with the allocation of total conversion expenditures to CPA categories in Figure 24, the strong employment performance of the three sectors 45, 27 and 28 is not surprising as the goods and services they produce also account for the largest shares of the economic impulse. However, it is noticeable that the demand for additional workers in sector 45 is disproportionately larger than its share of conversion expenditures. On the one hand, this can be explained by the labour-intensity of this sector compared to the more capital-intensive machinery and electrical equipment sectors. On the other hand, the MIO-ES model simulation results cover not only the direct effects of the conversion expenditures, but also the indirect and induced effects generated through the input-output links between economic sectors, so the total effect on one sector may be larger than the initial impulse.

Gross effects

Due to data unavailability, the estimated economic effects of vehicle retrofitting presented in this section do not account for the fact that the vehicle conversion expenditures imply reduced expenditures in other areas by the owners of the commercial vehicles. Given the scope of this study, the results also do not cover the declining production of conventionally driven vehicles. Therefore, the results represent gross rather than net effects and can be interpreted as providing an upper bound estimate of the potential overall effects.

Implications

What the results do indicate, however, is that the Austrian motor vehicle repair sector can expect substantial job gains through the demand to retrofit the remaining ICE-driven commercial vehicles by 2040. This represents an **opportunity to halt job losses in that sector** following the foreseeable decline in the need for car maintenance once the transition to battery electric vehicles fully takes off. In addition, the machinery and electrical equipment sectors stand to gain from the **production of conversion components (kits)**. Overall, vehicle conversions may help to **stabilise the labour market** during a time of technological transition. So that these positive effects can be realised, recommendations for policymakers are provided in section 9.3.

8 FURTHER VEHICLE CATEGORIES

Passenger cars, agricultural vehicles and other vehicles

In addition to the commercial vehicles of vehicle categories N1, N2, N3, M2 and M3, which are the main focus of this study, there are other vehicle categories that will be discussed in this chapter in terms of existing suppliers, relevant quantities and aspects of conversion costs (also in comparison to the purchase of new BEV). The vehicle categories considered in this basic overview are passenger cars, agricultural vehicles and other vehicles (mainly construction machines).

8.1 Overview of suppliers

Many car converters, hardly any converters of agricultural vehicles

In the research and analysis carried out for commercial vehicles with regard to existing providers of retrofit solutions on the market (see chapter 3), a parallel survey was also carried out to find out which other vehicle types (in addition to commercial vehicles) these companies also retrofit. Of the nearly 80 conversion companies researched, 56 also offer the conversion of passenger cars, with 14 of them describing their conversion procedure as series conversion. Most of the conversion companies retrofitting passenger cars therefore offer individual conversions, sometimes limited to certain vehicle makes or even vehicle models. Only 5 of the retrofitters surveyed stated that they also converted tractors or special vehicles.

8.2 Quantity structure and GHG reduction

The estimated conversion potential with regard to vehicle volumes and GHG emissions is shown below for further vehicle categories. A detailed quantitative estimation could only be made for the M1 category. For agricultural vehicles and special vehicles (e.g. construction machinery), a qualitative estimation was made.

8.2.1 Passenger cars

The methodology is described in sections 5.1.1 and 5.2.1.

Figure 28 illustrates the time series for the fleet composition of passenger cars (M1) from 2022 to 2050 assuming the “low scenario” according to EU targets for new zero-emission registrations (according to “Fit for 55”). The light green bars represent the absolute numbers of electric passenger cars. The light blue bars represent the remaining conventional vehicles with ICE in the PC fleet. The red line shows the percentage share of electric PC in new registrations. In the "low scenario", 100 % is reached in 2035.

Figure 29 shows the situation analogously for the "high scenario" according to Austria's targets for new zero-emission registrations (according to Austria's 2030 Mobility Master Plan). Here, 100 % of electric PC in new registrations is already reached in 2030.

Figure 27: Time series for fleet composition of vehicle category M1 in 2022 – 2050 for the "low scenario"

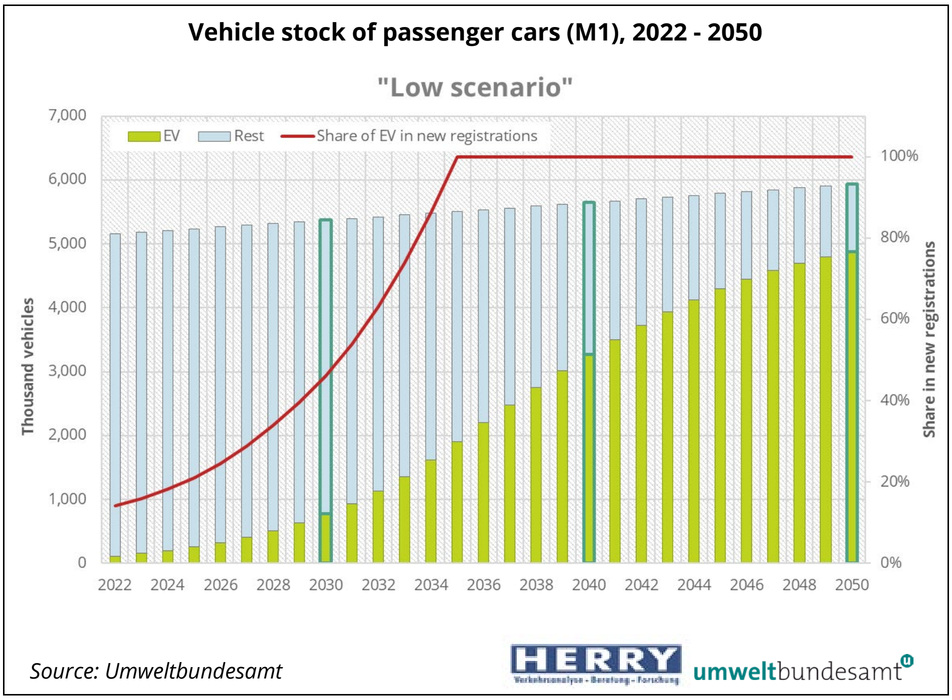


Figure 28: Time series for fleet composition of vehicle category M1 in 2022 – 2050 for the "high scenario"

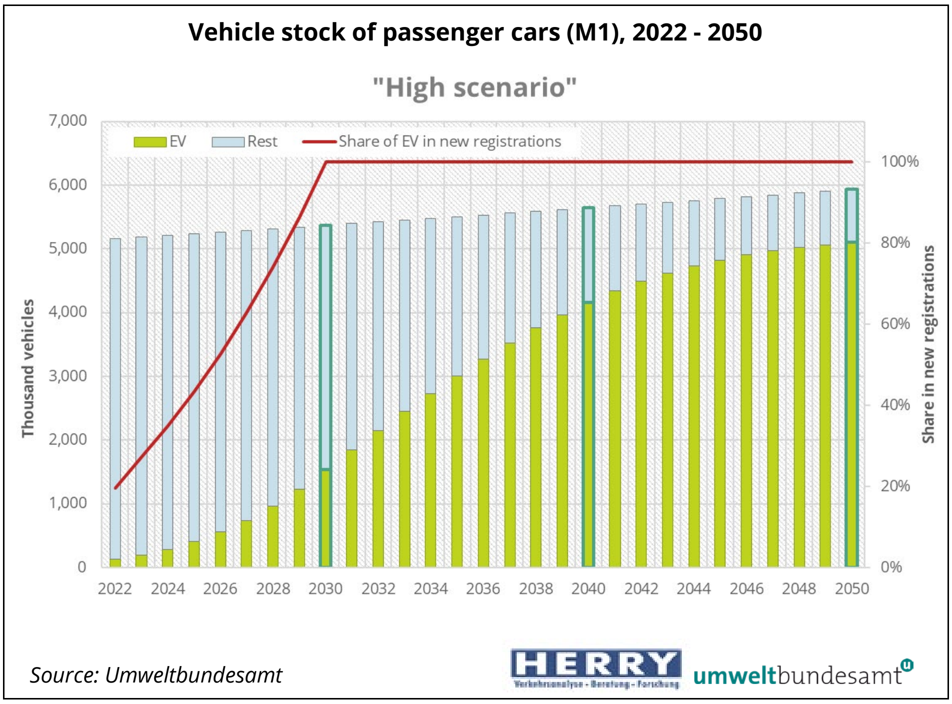


Table 12 gives an overview of the remaining PC with ICE in 2040, comparing the "low scenario" with the "high scenario".

Table 12: Remaining passenger cars with ICE in vehicle stock in 2040

Vehicle category	"Low scenario"	"High scenario"
Passenger cars (M1)	2,380,200	1,480,200

According to the method presented in section 5.2.1, for the remaining passenger cars with ICE in 2040, the GHG emissions are as shown in Table 13. This corresponds to the GHG reduction potential through retrofitting these passenger cars.

Table 13: GHG reduction potential in 2040 through retrofitting PC

Vehicle category	"Low scenario"	"High scenario"
Passenger cars (M1)	4,333,600 T $CO_{2\,e}$	2,695,000 T $CO_{2\,e}$

Greatest GHG reduction potential for passenger cars

Figure 9 in section 5.2.2 compares passenger cars with the different commercial vehicle categories regarding their GHG reduction potential. The greatest reduction potential comes from passenger cars, which is due to the high vehicle stock overall in this category.

8.2.2 Agricultural vehicles

The stock of agricultural vehicles (tractors and two-axle mowers) amounted to around 485,000 vehicles at the end of 2022 (STATISTIK AUSTRIA, 2022). A detailed quantitative estimation cannot be made for this vehicle category due to a lack of data regarding failure probabilities, vehicle stock development, annual mileage and emission factors. However, the quantity of vehicles in this category (comparable to category N1) suggests that retrofitting here also offers a high GHG reduction potential.

8.2.3 Special vehicles

There are no data available on the vehicle stock of special vehicles (e.g. construction machinery). However, in the manufacturing sector, 1.3 million tonnes of CO_2 equivalents came from mobile machinery (mainly construction machinery) in 2019 (UMWELTBUNDESAMT, 2022-b). For comparison, this amount is on par with the GHG emissions caused directly by LCV in 2019 (1.6 million tonnes of CO_2 equivalents) (UMWELTBUNDESAMT, 2022-b). This figure indicates that retrofitting offers considerable GHG reduction potential in the special vehicles sector too.

8.3 Costs

Passenger cars The conversion costs for passenger cars can vary greatly depending on the make, the vehicle size and the desired range (battery size). The discrepancy between battery costs for OEMs (new vehicles) and retrofitters (retrofitting) mentioned in chapter 6 is likely to be even higher for passenger cars, as significantly higher numbers of new cars are purchased in this sector than for commercial vehicles. The battery purchase price will therefore be correspondingly lower. This makes retrofitting less attractive than buying a new vehicle in this segment. In addition, comfort and safety features, which are constantly being developed further, play a more important role in this vehicle class than for commercial vehicles. This also makes a retrofit less attractive than a new purchase. The only argument in favour of retrofitting is the longer average service life in this segment in order to achieve the climate targets. However, this is somewhat offset by the earlier ban on the registration of combustion engines in the passenger car sector.

Agricultural vehicles Neither the costs for the purchase of new battery-powered agricultural vehicles nor the costs for the conversion of these vehicles can be estimated validly at present. There are still hardly any new battery electric vehicles on the market in this area. A few conversion companies offer a corresponding conversion. These are currently individual solutions and are accordingly expensive. The significantly longer average service life in this vehicle segment (compared to passenger cars and commercial vehicles) makes retrofitting attractive as in this case the basic vehicle can continue to be used. In addition, comfort features play a subordinate role in agricultural vehicles, which also makes retrofitting attractive. The large number of tractors and two-axle mowers may lead to volume effects in the prices for the battery and make the conversion even more attractive.

Other vehicles (mainly construction machines) The high purchase costs of special vehicles and the mostly very long useful lives of these vehicles make a conversion much more attractive compared to a new purchase. In addition, the costs for the battery in this sector should not differ so much between a new purchase and a retrofit since small numbers of units are produced in both cases. Thus, this vehicle category lends itself well to retrofitting and it is to be expected that this will be accepted accordingly.

9 CONCLUSION AND RECOMMENDATIONS FOR ACTION

This chapter summarises the conclusions of the study and derives recommendations for action. These are subdivided according to the following areas:

- Creating an appropriate legal framework;
- Setting economic incentives;
- Strengthening Austria as a business location.

9.1 Creating an appropriate legal framework

No uniform regulations at EU level

There are no uniform regulations regarding retrofitting in the Member States of the European Union. The legal situation regarding the (type-)approval of retrofitted vehicles is often complex and non-transparent. In some EU countries, approval for a modification is not available at all or only available if authorised by the OEM. The non-uniform regulations are an obstacle to the conversion of a large number of commercial vehicles. In Austria, only individual approvals of converted vehicles are possible so far, which may also be an impediment to a developing retrofit market. Both the retrofit industry representatives and the Austrian administration and legislator see the need for a uniform solution under European law. In the area of product liability, no relevant obstructive aspect was identified.

The following is a summary of the recommendations for the legal framework:

Commitment to the creation of a uniform legal framework

1. Creation of a uniform, harmonised legal framework in the European Union regarding the homologation process for converted vehicles: This should be done in consultation with policymakers, the administration and industry. The homologation process should be simplified and accelerated. At the same time, high quality and safety standards must be ensured. When designing the legal framework, all vehicle categories should be included, especially commercial vehicles. The aim is to establish a European retrofit market that enables a significant number of vehicle series to be retrofitted quickly and economically.

Certified workshops throughout the EU

2. Accreditation of certified workshops throughout the EU and for all of the EU: This means that there should be no confinement of workshops to a national territory (as is the case in France). In France, the retrofit can only be carried out by installers in the territory of France, which works against the establishment of an EU-wide retrofit market. Instead, certified workshops should be allowed throughout the territory of the EU.

Uniform knowledge in the technical services

3. Standardised build-up of knowledge in the various technical services with regard to retrofit as well as testing and approval procedures: For this purpose, the “Forum for Exchange of Information”, which was introduced with

Regulation (EU) 2018/858, could be used to exchange information between the EU countries and their technical services regarding retrofitting. It is recommended that the necessary competences and resources in the relevant (technical) institutions in Austria are built up.

Maintaining the permitted payload

4. Vehicle approval with regard to the maintenance of the permitted payload despite the increase in the tare weight through the vehicle conversion (because of the battery weight) should be examined under national law. (This is already partly implemented in Article 10b of Directive 96/53/EC.)

9.2 Setting economic incentives

The conversion of commercial vehicles with ICE to locally emission-free drive technologies will be necessary on a larger scale to be able to achieve the cross-sectoral goal of climate neutrality by 2040. However, without a subsidy (for the vehicle categories N1, N2, N3, M2 and M3) for retrofitting (with a simultaneous subsidy for new purchases), retrofitting will not get off the ground. In this case, it will not be possible for retrofitting capacities to be built up or for retrofitters to benefit from rising volumes and thus falling costs.

Creating a funding framework

5. National funding framework for retrofitting vehicles: This should reduce retrofit costs and stimulate the retrofit market in order to realise the potential retrofit volumes from 2030/2035. This support for retrofitting is recommended until 2030/2035. The continuation of this funding beyond this date should be examined in a timely manner. This will depend on the remaining conventional vehicle volumes and the maturity of the retrofit market by then.

Continuous adaption of subsidies to situation

6. The subsidy amount should be adjusted individually according to the vehicle class and should be in proportion to the subsidy for a new BEV purchase. An ongoing evaluation of the quantities and the TCO, comparing a new BEV purchase with a retrofit, is necessary in order to continuously adapt the subsidies to the situation and to do so at the appropriate time.

End customer as beneficiary of the subsidy

7. The funding regime should be designed such that it is only the end customer and not the retrofitter who is funded in order to ensure that this stimulates the retrofitting of the Austrian vehicle fleet. It should also be ensured that the vehicle for which the subsidy is granted is registered in Austria.

Reasonable costs

8. The type-approval of converted vehicles should not entail high costs because costs that are too high for the certification would prevent the economical conversion of significant quantities of vehicles. Therefore, a further economic incentive should be provided by reducing costs for the official type-approval of the converted vehicle.

9.3 Strengthening Austria as a business location

National retrofit task force

9. The retrofit market in Austria needs a push to be established. Therefore, a national task force on retrofitting is recommended in order to encourage networking between the retrofit industry players in Austria and to develop a criteria catalogue for retrofitting (along the lines of the one for Germany).

Training offensives for workers

10. Training offensives for the workforce in all sectors relevant to the retrofit market should be created. This is particularly important in the areas of maintenance and repair of motor vehicles (which can become certified retrofitting companies for commercial vehicles), manufacture of electrical equipment (for the production of electric motors, batteries and charging systems) as well as manufacture of machinery and equipment (for the production of other conversion kit components such as heating/cooling units). Retraining workers in the motor vehicles repair sector as retrofitters may help halt possible job losses in that area with the rise of less maintenance-intensive battery electric vehicles.

Establishment of production facilities in Austria

11. In addition, the establishment of production facilities in Austria for the necessary conversion components should be supported in order to fully utilise or even increase the economic potential (e.g. production facilities for batteries). Subsidies for the conversion of production from combustion engine to electric drives can also be considered for this purpose.

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ANNEX A – QUESTIONNAIRE

The Environment Agency Austria and Herry Consult GmbH are currently working on a study on behalf of the Federal Ministry of the Republic of Austria for Climate Action, Environment, Energy, Mobility, Innovation and Technology, which examines the potential and framework conditions for the conversion of existing vehicles (trucks and buses) to locally emission-free technologies. Essential parts of the study are a market analysis, the analysis of the legal framework as well as a comparative analysis of the economic efficiency of this solution (also in comparison to buying new).

Therefore, major suppliers of retrofit solutions are being asked to provide information about their solutions and offerings and to point out the problems with which these companies are confronted. For this purpose, a questionnaire has been prepared, which is being sent to selected retrofit companies in German-speaking countries with the request to complete.

We kindly ask you to return the questionnaire by 18 May 2022.

You are also welcome to submit supplementary material and information that answers the questions.

General / Legal and guarantee issues

- In which countries have you already gone through a homologation process for converted vehicles or the approval process for individual converted vehicles?
- Were there significant differences between different EU countries?
- Did you encounter any obstacles in the process? If so, which ones?
- How was your experience with the approval process specifically in Austria? What legal obstacles do you see specifically in Austria?
- Is there a need for harmonisation at European level? If so, where?
- What are the key standards, norms and regulations to which your conversion kit is designed, manufactured, assembled and approved?
- What guarantee periods are given for the individual components?
  - Batteries
  - Fuel cell
  - Total conversion kit / total conversion solution
- Do you have partner workshops for regular maintenance and repairs?
- Is the homologation process part of your service?
- In your opinion, what further measures beyond those you have already outlined in response to the above questions are needed at Austrian and European level to enable your company to make its retrofit offering more attractive and to enable the retrofit issue in general to gain momentum?

Your company's retrofit offering

- Which conversion do you offer (currently / in future)?
  - Technologies
    - BEV
    - FCEV
    - Other – which one?
  - Vehicle categories (passenger cars, trucks N1/N2/N3, buses M2/M3, other?)
  - Vehicle makes (per vehicle category if different)
  - Do you offer the whole conversion or only the conversion kit (or both options)?
  - If you only offer the conversion kit, do the converters have to meet specific requirements to be allowed to buy the kit? Which ones?
- How old are the vehicles that are currently being converted (from/to, on average) per vehicle category?
- From and up to what age of the vehicles to be converted (per vehicle category)
  - is the retrofit (technically) possible?
  - is the retrofit reasonable from your point of view?
- Will this age relevance change up to 2040?
- Retrofit capacity
  - currently?
  - in future (by when?)?

Technology

- Which retrofit components does your retrofit (to BEV) include? Please mark with "X" if applicable; if different per vehicle category, then please specify accordingly:
  - Electronic control
  - Battery
  - Charging system
  - Current transformer
  - E-motor
  - Gearbox
  - Drive axle
  - Other components (e.g. auxiliary units driven by the combustion engine). Which ones?
- Which retrofit components does your retrofit (to FCEV) include? Please mark with "X" if applicable; if different per vehicle category, then please specify accordingly:
  - Electronic control

  - Battery
  - Battery management system
  - Current transformer
  - E-motor
  - Fuel cell system
  - Filler neck
  - Hydrogen tank
  - Gearbox
  - Drive axle
  - Other components (e.g. auxiliary units driven by the combustion engine). Which ones?
- Which components do you currently and will in the future offer in series production (conversion kit)? Which components must always be custom-made in any case?
  - Kit for all vehicles of one vehicle category
  - Kit for all vehicles of one manufacturer per vehicle category
  - Kit for a specific vehicle type per manufacturer and vehicle category
- What average service life (in vehicle kilometres) can be expected for the individual new components?
- Which batteries are installed, and why these?
- Which batteries will be installed in the future, and why these (e.g. solid state battery)?
- Which electric motor (type) is installed, and why this?
- Change in vehicle weight and resulting payload as a result of the conversion (differentiated by vehicle category), currently and in the future (please also state the battery capacity used as a basis for the weight analysis)
- Change in the distribution of mass between the axles due to the conversion (with the above battery capacity)

Retrofit costs currently and in the future, differentiated by cost component and vehicle type

- Cost components and their costs (average, differentiated by vehicle category):
  - Dismantling of the combustion engine (and exhaust, fuel tank, radiator, air filter) (personnel costs)
  - Dismantling of gearbox and drive axle (if relevant) (personnel costs)
  - Installation of the new components for BEV or FCEV (personnel costs)
  - Necessary vehicle body modification (if necessary due to space constraints) (personnel costs)
  - Necessary vehicle body modification (if necessary due to space constraints) (material costs)
  - Cost of BEV components

    - Electronic control
    - Battery (EUR/kWh)
    - Charging system
    - Current transformer
    - E-motor
    - Gearbox
    - Drive axle
    - Other components (e.g. auxiliary units driven by the combustion engine). Which ones?
  - Cost of FCEV components
    - Electronic control
    - Battery (EUR/kWh)
    - Battery management system
    - Current transformer
    - E-motor
    - Fuel cell system
    - Filler neck
    - Hydrogen tank
    - Gearbox
    - Drive axle
    - Other components (e.g. auxiliary units driven by the combustion engine). Which ones?
  - Other cost components not already listed above
  - Overhead costs (if not included above)
- Development trends in the costs of the cost components listed (increasing, constant, decreasing):
  - Dismantling of the combustion engine (and exhaust, fuel tank, radiator, air filter) (personnel costs)
  - Dismantling of gearbox and drive axle (if relevant) (personnel costs)
  - Installation of the new components for BEV or FCEV (personnel costs)
  - Necessary vehicle body modification (if necessary due to space constraints) (personnel costs)
  - Necessary vehicle body modification (if necessary due to space constraints) (material costs)
  - Cost of BEV components
    - Electronic control
    - Battery (EUR/kWh)
    - Charging system
    - Current transformer
    - E-motor
    - Gearbox

    - Drive axle
    - Other components (e.g. auxiliary units driven by the combustion engine). Which ones?
  - Cost of FCEV components
    - Electronic control
    - Battery (EUR/kWh)
    - Battery management system
    - Current transformer
    - E-motor
    - Fuel cell system
    - Filler neck
    - Hydrogen tank
    - Gearbox
    - Drive axle
    - Other components (e.g. auxiliary units driven by the combustion engine). Which ones?
  - Other cost components not already listed above
  - Overhead costs (if not included above)
- Market price for the conversion (average, differentiated by vehicle category, with a typical battery size; please indicate the underlying battery capacity)

ANNEX B – LIST OF RETROFIT COMPANIES

Table 14: List of retrofit companies

Company name	Converted vehicle categories	Conversion to which drive technology?	Country
ABT GmbH	LCV (VW Caddy T6)	BEV / FCEV	DE
Akkumobil	PC, motorcycles	BEV	AT
Alternative Vehicles Technology	PC, motorcycles	BEV	GB
Auto libre	PC, LCV	BEV	UY
BEDEO	PC, LCV, HDV	BEV	GB
BharatMobi	PC	BEV	IN
Box-E	PC	BEV	IT
Canadian Electric Vehicles Ltd	PC, LCV, HDV	BEV	CA
CARWATT	PC, buses, special vehicles, tractors, boats, trains	BEV	FR
CellProp Pvt Ltd	LCV	BEV	IN
Classic Ecars Broedersdorff & Koenzen GmbH	PC	BEV	DE
Clean Logistics SE	HDV, buses	FCEV	DE
Designwerk Technologies AG	HDV	BEV	CH
DIYev	PC, LCV, HDV	BEV	USA
E-Cap Mobility GmbH	PC, LCV, HDV, buses, boats	BEV / FCEV	DE
E-CAR-TECH Consulting GmbH	PC, LCV, HDV, tractors	BEV	DE
eClassics GmbH & Co. KG	PC, LCV	BEV	DE
Ecotuned Automobile	PC, LCV	BEV	CA
Eddy Motorworks	PC	BEV	US
EFA-S GmbH	PC, LCV, HDV, construction machinery	BEV	DE
Electric Classic Cars	PC (classic cars)	BEV	GB
Electromod Garage	PC	BEV	US
Ele-Driveco	PC	BEV	PL
elerra motiv GmbH	PC, LCV, HDV, buses, special vehicles	BEV	DE
emovum GmbH	LCV, HDV	BEV	DE
e-Néo	HDV, buses, tractors, special vehicles	BEV / FCEV	FR
e-Roadster	Motorsport vehicles	BEV	FR
Etrio	PC, LCV	BEV	IN
EVDrive	PC, LCV, HDV	BEV	US

Company name	Converted vehicle categories	Conversion to which drive technology?	Country
EV4U Custom Conversions	PC, LCV, HDV	BEV	US
E-Works Mobility GmbH	LCV, HDV	BEV	DE
Flash Drive Motors LLC	PC	BEV	US
Fleck GmbH	PC, LCV, boats	BEV	DE
FRAMO GmbH	HDV	BEV / FCEV	DE
Green Corp Konnection	PC, boats, special vehicles	BEV / FCEV	FR
Green Motors Inc.	PC	BEV	US
Green Shed Conversions	PC, LCV, HDV	BEV	US
I SEE Electric Busses GmbH	Buses	BEV	DE
I SEE Electric Trucks GmbH	LCV	BEV	DE
Inteso GmbH	PC	BEV	AT
Jaton Racing	PC	BEV	ES
Kreisel Electric GmbH & Co. KG	PC, LCV, boats	BEV	AT
Leiser Electric GmbH	PC	BEV	CH
London Electric Cars	PC	BEV	GB
Lorey Maschinenbau GmbH	PC, ships, carriages, tractors, excavators, etc.	BEV	DE
Lormauto	PC	BEV	FR
Magna	LCV, HDV	BEV	DE
Make Mine Electric	PC	BEV	US
Mini	PC (classic minis)	BEV	GB
MONA Mobility	PC, LCV, HDV, buses, construction machinery	BEV / FCEV	FR
Monceau Automobiles	PC (classic cars)	BEV	BE
Murschel Electric Cars GmbH	PC (mainly old VW models)	BEV	DE
NAEXT Automotive GmbH	PC	BEV	DE
NEOTRUCKS	HDV	BEV	FR
New Electric Automotive	PC, LCV, HDV, tractors	BEV	NL
Novum Tech	PC, HDV, agricultural vehicles, construction machinery	BEV	FR
ORTEN Electric-Trucks GmbH	LCV, HDV	BEV / FCEV	DE
Oz Corporation Co., Ltd.	PC	BEV	JP
Pacific EV Solutions, LLC	PC, LCV	BEV	US
Pepper Motion GmbH	HDV, buses	BEV / FCEV	DE

Company name	Converted vehicle categories	Conversion to which drive technology?	Country
Phoenix Mobility	PC, LCV, HDV	BEV	FR
Pixy Electric Cars Pvt. Ltd	PC	BEV	IN
QUANTRON AG	LCV, HDV, buses, working machines, trains, boats	BEV / FCEV	DE
RACEnergy	LCV (3 wheels)	BEV	IN
RaleighEV	PC	BEV	US
REV Mobilities	PC, LCV, HDV, buses	BEV / FCEV	FR
R-FIT	PC (vintage)	BEV	FR
RiPower GmbH	PC, LCV, HDV, bicycles, motorcycles, quads, boats	BEV	DE
Saget	PC (classic beetle)	BEV	VE
Shenzhen Greenwheel Electric Vehicle Group Co.,Ltd	PC, LCV, HDV	BEV	CN
Silent Classics	PC	BEV	GB
Singular Motion EV	PC	BEV	US
SRS Customs GmbH	PC, LCV	BEV	AT
Stealth EV	PC	BEV	US
Transition-one	PC, LCV	BEV	FR
Turn-E GmbH	PC (vintage), boats	BEV	DE
Voith GmbH & Co. KGaA	Buses	BEV	DE
Voltia	PC	BEV	SK
Zelectric Motors LLC	PC	BEV	US
Zero21 Renewable Energy Solutions PVT LTD	LCV (3 wheels)	BEV	IN
Zero Labs	PC, LCV	BEV	US

ANNEX C – TIME SERIES FOR FLEET COMPOSITION

The figures for the time series for the fleet composition of all vehicle categories (N2, N3, semi-trailers and M2/M3) are provided below. The "low scenario" and the "high scenario" are depicted for each vehicle category.

Figure 29: Time series for fleet composition of vehicle category N2 in 2022 – 2050 for the "low scenario"

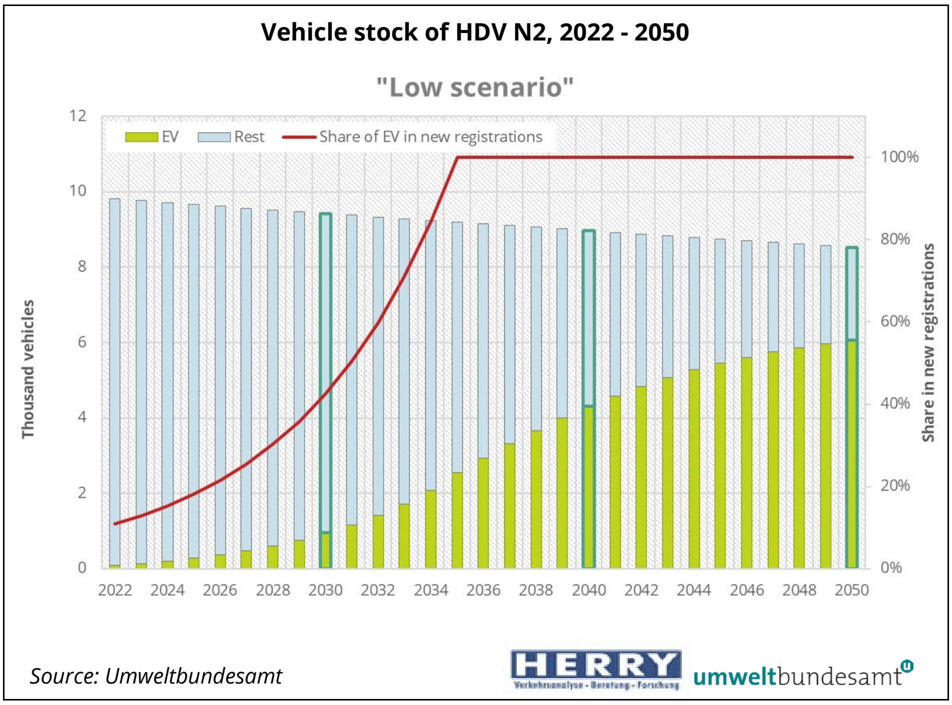


Figure 30: Time series for fleet composition of vehicle category N2 in 2022 – 2050 for the "high scenario"

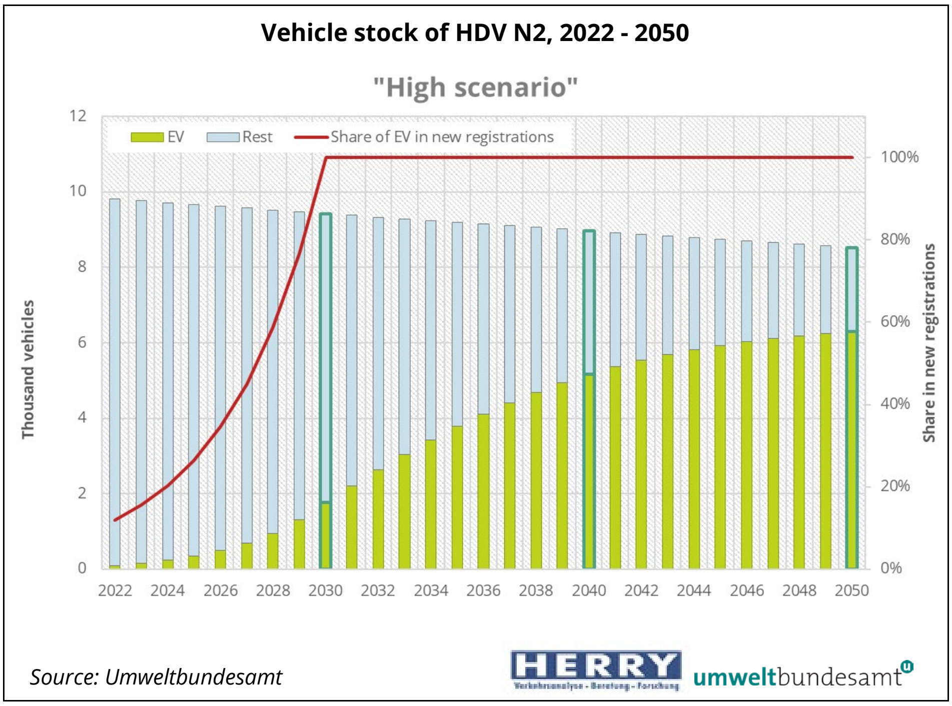


Figure 31:
Time series for fleet composition of vehicle category N3 in 2022 – 2050 for the "low scenario"

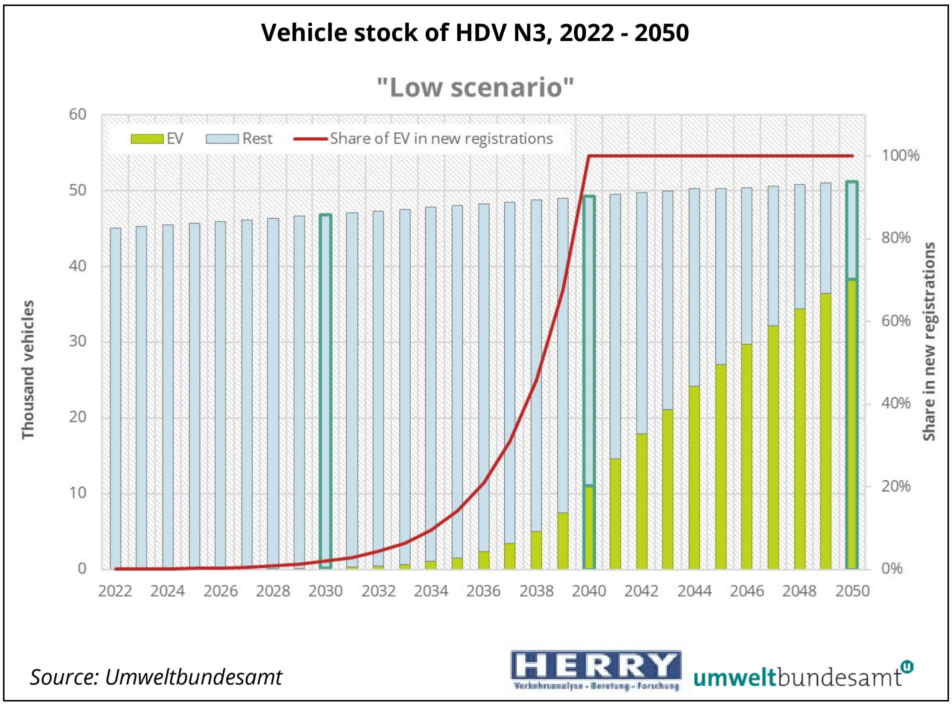


Figure 32:
Time series for fleet composition of vehicle category N3 in 2022 – 2050 for the "high scenario"

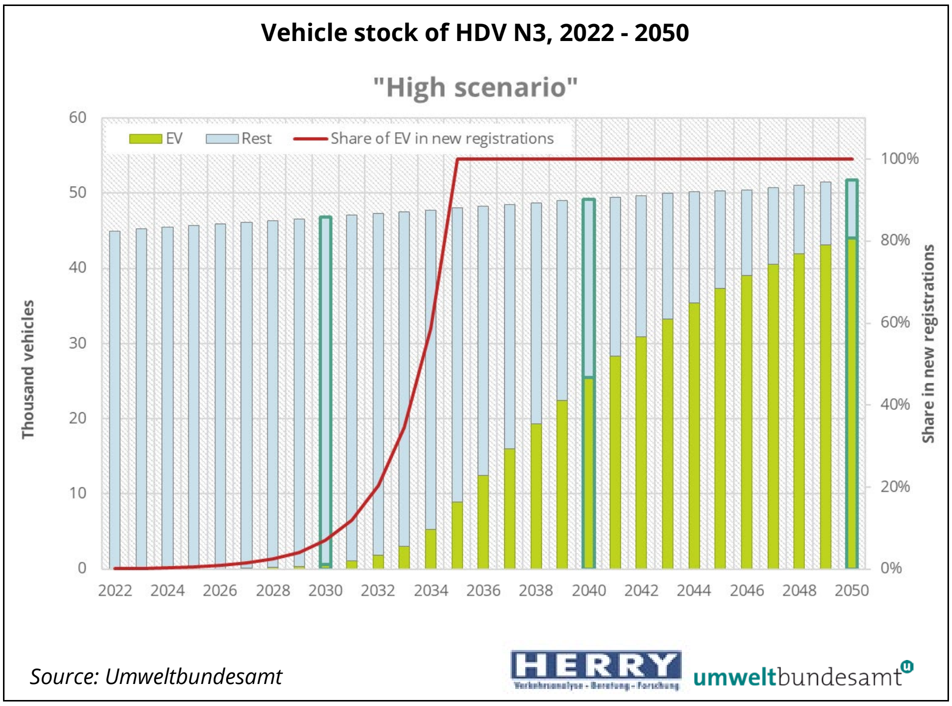


Figure 33: Time series for fleet composition of semi-trailers vehicle category in 2022 – 2050 for the "low scenario"

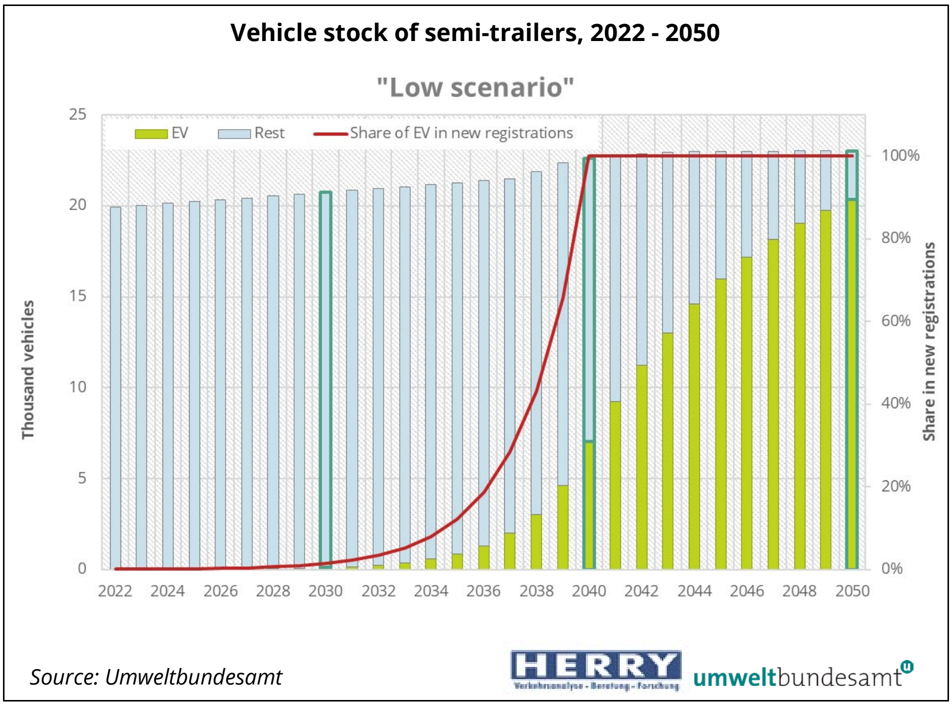


Figure 34: Time series for fleet composition of semi-trailers vehicle category in 2022 – 2050 for the "high scenario"

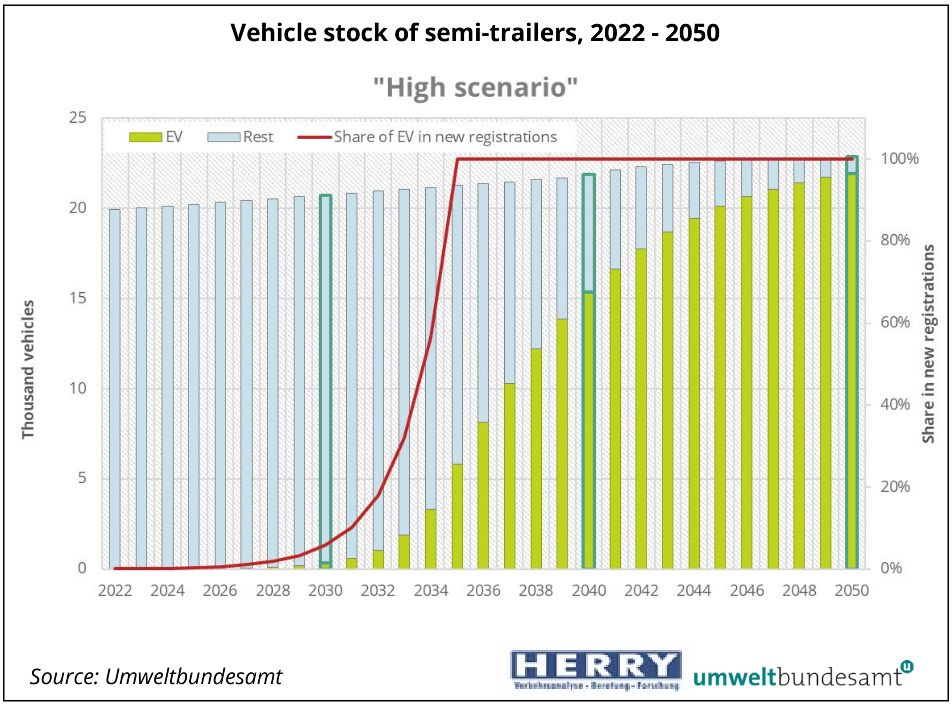


Figure 35: Time series for fleet composition of vehicle category M2/M3 in 2022 – 2050 for the "low scenario"

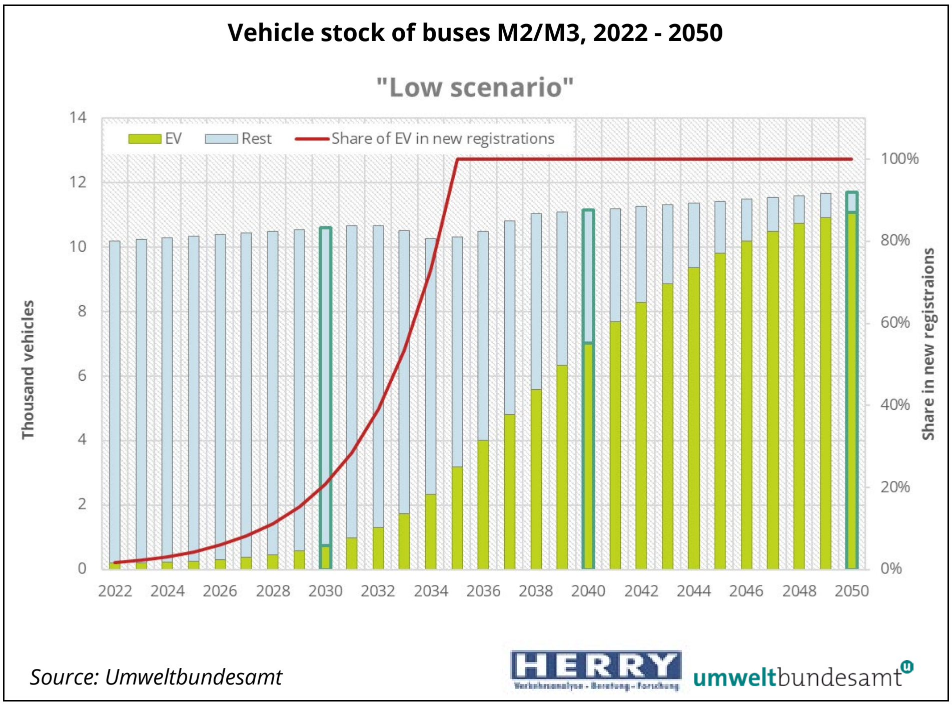
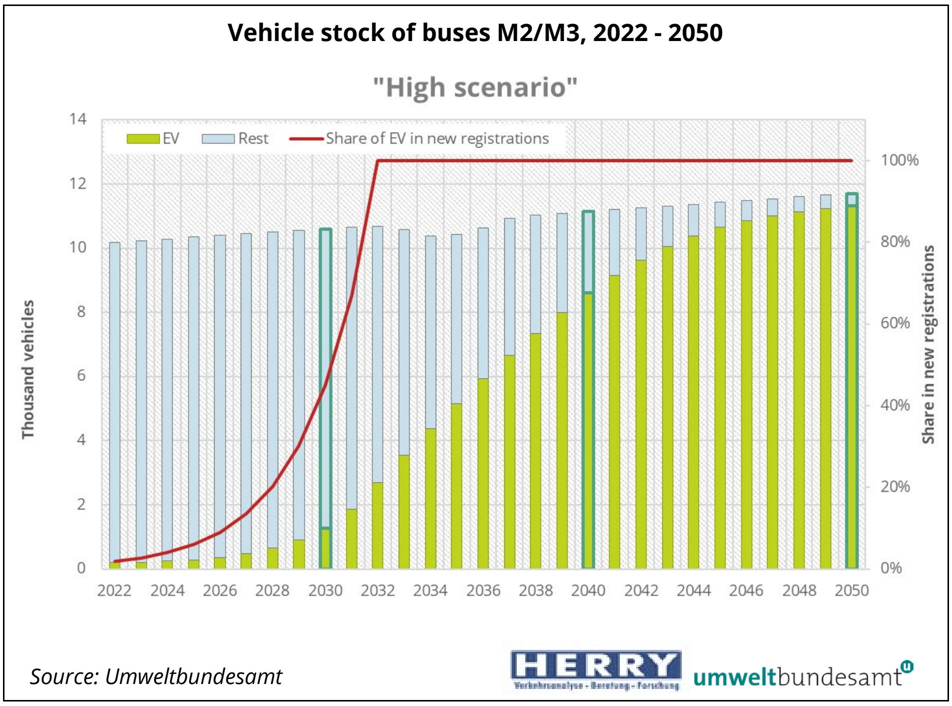


Figure 36: Time series for fleet composition of vehicle category M2/M3 in 2022 – 2050 for the "high scenario"



Umweltbundesamt GmbH
Spittelauer Laende 5
1090 Vienna/Austria

Tel.: +43-1-313 04

office@umweltbundesamt.at
www.umweltbundesamt.at

In order to achieve the national goal of climate neutrality by 2040, only zero-emission vehicles are to be newly registered between 2030 and 2035 according to Austria's 2030 Mobility Master Plan. Since vehicles are often used for longer than the resulting five to ten years, at the same time measures must be taken to green the 'old vehicle stock'.

One possibility is to convert conventionally powered second-hand vehicles from combustion engines to electric drives. The study deals with the resulting challenges and potentials for the economy in Austria and abroad and provides an estimate of the possible vehicle volumes, with a focus on commercial vehicles. It also indicates necessary changes in the relevant national and international legislation, options for economic incentives and chances for strengthening Austria as a business location.

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