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GREENROAD

Guidelines enabling renewable energy supply for zero emission road traffic infrastructure

Final Report

Vienna, April 28th, 2023

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EXECUTIVE SUMMARY

GREENROAD project goals

The main objectives of the GREENROAD study are:

- to provide a **national quantity structure** and detailed **spatial allocation** for the projected requirements of **zero emission infrastructure** for up to 2040,
- to estimate the expected infrastructure costs,
- to evaluate the need for public support measures and
- to recommend necessary complementary actions.

GREENROAD zero emission infrastructure projection model

For the purpose of the study, a specific calculation model for projecting the spatially allocated need for zero emission charging and refuelling infrastructure has been developed. The main model input elements are:

- projected overall energy demand and corresponding traffic performance data by vehicle categories and drive types according to the underlying scenarios of Environment Agency Austria
- traffic model analyses derived from the National Traffic Model VMÖ
- a set of adjustable input parameters and variables

Projected demand for publicly accessible zero emission infrastructure

Publicly accessible occasional/destination charging

By 2030, approx. **70 300** and **by 2040** approx. **108 900 publicly accessible destination charging points** for cars and light commercial vehicles are required. For this use case, the attractivity of a municipality for shopping, leisure or touristic trips is a key factor for the charging demand potential. Hence, metropolitan areas are dominant with the highest numbers of required charging points. In addition, demand accumulations in well-known touristic destinations can be clearly identified.

Publicly accessible range extension charging

By 2030 approx. **3 800** and **by 2040** approx. **3 900 publicly accessible high-power range extension charging points** for cars and light commercial vehicles are required. In contrast to private and publicly accessible destination charging, the demand peak for high-power range extension charging is already expected in the early 2030s. After that, with a growing number of available private charging stations and higher average vehicle ranges, a saturation effect occurs and the demand remains relatively stable until (and after) 2040. Due to the combination of route length and traffic volumes, the A1 motorway has by far the highest need of demand, followed by A2, A9, A10 and A12. Apart from the motorway network, which plays a dominant role for range extension charging, well-known routes in the national road network that have a high relevance for traffic with longer trip distances, can be identified. Examples are the routes along B100 (Drautal), B108 (Felbertauern), B179 (Fernpass), B180 (Reschenpass) or B320 (Ennstal).

Publicly accessible HDV charging

By 2030 approx. **1 400** and **by 2040** approx. **1 600 publicly accessible HDV charging points** are required. Thereof, around **70 %** should be **overnight-chargers** (mainly located at already existing motorway rest and parking areas) with approx. 150 kW and **30 % megawatt chargers**. Like for cars and light commercial vehicles, the demand peak for high-power charging is already expected during the 2030s. After that, there occurs a saturation effect and the demand for publicly accessible HDV charging remains relatively stable until (and after) 2040. The A1 motorway has by far the highest demand need, followed by A2, A10, A9, A8 and A12, which more or less represent the most important heavy vehicle transit routes in Austria. Apart from the motorway network, which of course plays a clearly dominant role here, only single routes in the national road network that have a certain relevance for long-distance HGV traffic like especially the B320 (Ennstal) can be identified. In the event that selected motorway sections along the TEN-T network will be equipped with ERS (Electric Road Systems), the projected number of required HDV charging points could be reduced to a certain degree.

Publicly accessible H2 stations

The model results determine a demand of around **70 publicly accessible H2 refuelling points by 2030** and **130 by 2040**. At the moment the pressure on publicly accessible H2 refuelling infrastructure is not as crucial as for electric charging infrastructure. The objective is to offer a basic refuelling infrastructure in line with the European development goals especially along the TEN-axes.

Public transport bus charging

By 2030, around **1 300** and **by 2040** around **1 900 charging points** for buses are required. It is assumed that these charging points will mainly be located at bus depots (mainly for overnight charging) on one hand and at relevant stations of the public transport networks (mainly for recharging during the day) on the other hand.

Costs

The **total costs for the required public zero emission infrastructure** (including publicly accessible fast charging, occasional charging at destination locations like supermarkets, leisure facilities, hotels etc. as well as public on-street parking in urban areas) **amount to 3.3 billion Euro until 2040.** This corresponds to around **181 million Euro per year on average** as from 2022. From a temporal perspective, the highest investments with more than 1.1 billion Euro will be necessary in the period between 2025 to 2030 with a flattening trend in the 2030s (around nearly 1 billion Euro until 2035 and another 700 million Euro until 2040). Because the e-vehicle market ramp-up is currently lagging behind compared to the underlying Transition Mobility Scenario, the demand projection for 2025 is likely to be overestimated. Thus, the growth rate in later years will need to be accordingly steeper. Depending on how fast the market ramp-up can catch up with the target path, a temporal shift of the costs from the 2020s to the 2030s can be assumed. The lion's share of the total public costs with **79 %** on average is due to the expansion of **publicly accessible charging infrastructure for e-cars and light commercial vehicles**. This is in turn to a large extent (on average 66 % of total costs) driven by the need for a high number of publicly accessible or semi-publicly accessible charging points for occasional/destination charging at shopping and leisure facilities as well as at public on-street parking spaces in urban areas. High-power fast charging infrastructure for cars and light vehicles amounts to 13 % of total costs on average over the years. Another **21 %** are required for **heavy duty vehicles infrastructure** (publicly accessible charging points and H2 stations).

Evaluation of the need for public support

Currently, there are about 15 000 publicly accessible charging points available in Austria (approx. 14 300 destinations and 700 range extension charging points according to the GREENROAD use case definition). GREENROAD results show that by 2040 a total number of around 113 000 publicly accessible charging points for cars and light commercial vehicles (thereof approx. 109 000 destination and nearly 4 000 range extension charging points) will be required. Hence, based on the current state in 2022, the **expansion factors** required to reach the projected numbers are **4.9** (2030) and **7.6** (2040) for **destination charging** respectively **5.4** (2030) and **5.6** (2040) for **range extension charging**. For the assessment of the required expansion speed, a comparison with the network expansion during the last two years has been conducted. For the use case **destination charging**, about 3 200 additional charging points per year have been implemented between early 2021 and early 2023. This **expansion rate has to be more than doubled to around 7 000 charging points per year** in order to reach the projected demand in 2030. Between 2030 and 2040 around 3 900 additional charging points per year are sufficient. For the use case **range extension**, the expansion speed between early 2021 and early 2023 amounts to around 500 charging points per year. From a national perspective, a growth rate of **400 high-power charging points per year until 2030** would be sufficient, but with the addition of keeping the required geographical coverage in mind. Between 2030 and 2040, due to the occurring saturation effect around 10 additional high-power charging points per year are sufficient. For the HDV sector no gap analysis was conducted because there are in fact no existing charging stations available at the moment. The general findings apply analogously for heavy duty vehicle infrastructure. Market entrants have to take on the economic risk, remedy the current inadequacy of recharging infrastructure and ensure that new charging infrastructure meets the necessary technical standards and geographical coverage. The results of GREENROAD show a need for funding to accelerate the market ramp-up and support the development of charging infrastructure.

Recommendations for action

In addition to the necessary modal shift according to the goals of the National Mobility Masterplan 2030, an intensive expansion of renewable energies in Austria is of central importance for achieving climate neutrality in the traffic-sector. The GREENROAD results show a substantial need for expansion of zero emission charging and refuelling infrastructure, whereby there are significant differences between use cases as well as on regional level. Based on the modelled charging demand approx. 70 300 destination and 3800 high-power range extension charging points are required in Austria by 2030 respectively 108 900 destination and 3900 range extension charging points by 2040. Based on the current state in 2022, the expansion factors required to reach the projected numbers are 4.9 (2030) and 7.6 (2040) for destination charging respectively 5.4 (2030) and 5.6 (2040) for range extension charging. For the HDV sector, approx. 1 400 publicly accessible HDV charging points are required by 2030 and 1 600 by 2040 in Austria for heavy goods vehicles and coaches. Thereof, around 70 % should be overnight-chargers with approx. 150 kW and 30 % so-called megawatt chargers. For both light vehicles and HDV the **demand peak for high-power range extension charging** is already expected **in the early 2030s**. After that, there occurs a saturation effect and the demand for fast range extension charging remains relatively stable until (and after) 2040. Therefore, **the majority of the required high-power range extension charging points should already be built until 2030** in order to prevent further delays of the e-mobility market ramp-up.

Because the market ramp-up is currently lagging behind compared to the transition scenarios, the demand projection for 2025 is likely to be overestimated. Thus, the growth rate between 2025 and 2040 will need to be accordingly steeper. Considering this **urgent need for action**, a central conclusion of the study is that a **public market intervention in the form of financial fundings for zero emission infrastructure is inevitable**. During the completion phase of the present study, an important step has already been implemented by the launch of the ENIN funding program in early 2023.

Regarding hydrogen technology, the results show a requirement of around 70 public publicly accessible H2 refuelling points by 2030 and 130 by 2040. As larger H2 vehicle fleets are not likely to emerge before 2030 and especially pioneer fleet operators and larger transport operators predominantly will build their own private infrastructure, at the moment **the need for publicly accessible H2 refuelling infrastructure is not as crucial as for the electric charging infrastructure**. The principal objective is to offer a basic refuelling infrastructure in line with the European development goals especially along the TEN-axes. It is strongly recommended to develop consistent technical standards for the construction of hydrogen filling stations.

In general, it has become evident that the required expertise and workforce are currently not available to the necessary extent. In order to foster a rapid infrastructure expansion, appropriate **educational and labour market measures** have to be seized.

KURZFASSUNG

Projektziele

Die wesentlichen Projektziele der GREENROAD Studie waren

- die Bereitstellung eines **nationalen Mengengerüsts** und einer detaillierten **räumlichen Verortung** für den prognostizierten **Bedarf an Zero Emission Infrastruktur** (E-Ladepunkte und H2-Stationen) bis 2040,
- die Abschätzung der zu erwartenden Infrastrukturkosten,
- die Evaluierung des Bedarfs an öffentlichen Fördermaßnahmen und
- die Empfehlung erforderlicher Begleitmaßnahmen.

GREENROAD Prognosemodell für Zero Emission Infrastruktur

Im Rahmen der Studie wurde ein spezifisches Berechnungsmodell für die räumlich hochauflösende Prognose des Bedarfs an Zero Emission Lade- und Betankungsinfrastruktur entwickelt. Die wesentlichen Modellinputs sind:

- Prognostizierter Gesamtenergiebedarf und korrespondierende Verkehrsleistung nach Fahrzeug- und Antriebstyp basierend auf den zugrundeliegenden Szenarien des Umweltbundesamts
- Verkehrsmodellanalysen basierend auf dem nationalen Verkehrsmodell VMÖ
- Definiertes Set an anpassbaren Parametern und Variablen

Prognostizierter Bedarf für öffentliche Zero Emission Infrastruktur

Öffentliches Destination Charging bzw. Gelegenheitsladen

Bis 2030 sind ca. **70 300** und **bis 2040** ca. **108 900** öffentliche Destination-Ladepunkte für Pkw und leichte Nutzfahrzeuge erforderlich. Bei diesem Use Case ist die Attraktivität einer Gemeinde für Einkaufs- Freizeit- oder touristische Fahrten ein entscheidender Faktor für das Potenzial der Ladenachfrage. Daher dominieren hier städtische Regionen mit den größten Zahlen hinsichtlich der benötigten Ladepunkte. Weiters können aber auch Nachfrage-Häufungen in bekannten touristischen Destinationen klar identifiziert werden.

Öffentliches Range Extension Laden

Bis 2030 werden ca. **3 800** und **bis 2040** ca. **3 900** öffentliche Hochleistungs-Schnellladepunkte für Pkw und leichte Nutzfahrzeuge benötigt. Im Gegensatz zum privaten Laden und zum öffentlichen Destination Charging ist die Nachfragespitze für Hochleistungsladen zur Reichweitenverlängerung bereits in den frühen 2030er Jahren zu erwarten. Danach tritt, bedingt durch eine steigende Zahl an verfügbaren privaten Ladepunkten und größere durchschnittliche Fahrzeugreichweiten, ein Sättigungseffekt ein und die Nachfrage bleibt bis 2040 (und danach) relativ stabil. Aufgrund der Kombination aus Streckenlänge und Verkehrsaufkommen weist die Autobahn A1 das mit Abstand größte Nachfragepotenzial auf, gefolgt von A2, A9, A10 und A12. Abseits des A+S Netzes, welches eine dominante Rolle für das Range Extension Laden einnimmt, stechen auch einzelne Routen im Landesstraßennetz mit entsprechender Relevanz für Verkehre mit längeren Fahrtweiten hervor. Beispiele dafür sind die B100 (Drautal), B108 (Felbertauern), B179 (Fernpass), B180 (Reschenpass) oder B320 (Ennstal).

Öffentliches Laden für Schwerverkehr

Bis 2030 werden ca. **1 400** und **bis 2040** ca. **1 600** öffentliche Ladepunkte für den Schwerverkehr benötigt. Davon entfallen ca. 70 % auf sogenannte Overnight-Charger (hauptsächlich an bestehenden Rastanlagen am A+S Netz) mit ca. 150 kW und 30 % auf Megawatt-Charger. Ähnlich wie für Pkw und leichte Nutzfahrzeuge wird auch im Schwerverkehr die Nachfragespitze für Hochleistungsladen im Laufe der 2030er Jahre erwartet. Danach tritt ein Sättigungseffekt ein und die Nachfrage bleibt bis 2040 (und danach) relativ stabil. Die Autobahn A1 hat mit Abstand das größte Nachfragepotenzial, gefolgt von A2, A10, A9, A8 und A12, womit im Wesentlichen die wichtigsten Schwerverkehrs-Transitrouten durch Österreich abgedeckt sind. Abseits des A+S Netzes, welches klarerweise die dominante Rolle spielt, haben nur einzelne Routen im Landesstraßennetz eine gewisse Relevanz für Langstreckenverkehre im Schwerverkehr, beispielsweise die B230 durch das Ennstal. Derzeit ist noch unklar, welche Rolle sogenannte Electric Road Systems (ERS, Oberleitungssysteme auf Autobahnen) langfristig spielen werden. Für den Fall, dass ausgewählte Autobahnabschnitte entlang des TEN-T Netzwerks mit ERS ausgestattet werden, könnte die prognostizierte Anzahl an Schwerverkehrs-Ladepunkten in einem gewissen Ausmaß reduziert werden.

Öffentliche H2-Stationen

Die Modellergebnisse prognostizieren einen Bedarf von ca. **70 öffentlichen H2-Tankstellen bis 2030** und **130 bis 2040**. Derzeit ist die Dringlichkeit für eine öffentliche H2-Betankungsinfrastruktur nicht ganz so hoch wie für die öffentliche elektrische Ladeinfrastruktur. Das Ziel ist hier, eine Basis-Versorgung im Einklang mit den Entwicklungszielen auf europäischer Ebene zu schaffen, insbesondere entlang der TEN-Achsen.

Laden von ÖV-Bussen

Bis 2030 werden ca. **1 300** und **bis 2040** ca. **1 900** Ladepunkte für ÖV-Busse benötigt. Es ist davon auszugehen, dass diese Ladepunkte einerseits hauptsächlich in Busdepots (vor allem für Overnight-Charging) und andererseits an relevanten Stationen des ÖV-Netzes (für Nachladen untertags) situiert sein werden.

Kosten

Die Gesamtkosten für die Errichtung der benötigten Zero Emission Infrastruktur (inkl. öffentliches Schnellladen, Gelegenheitsladen an Zielorten wie Supermärkten, Freizeiteinrichtungen, Hotels etc. sowie Laden auf öffentlichen Parkplätzen im städtischen Straßenraum) belaufen sich auf **3.3 Milliarden Euro bis 2040**. Das entspricht **durchschnittlich 181 Millionen Euro pro Jahr** beginnend mit 2022. Aus zeitlicher Perspektive sind die größten Investitionen mit mehr als 1.1 Milliarden zwischen 2025 und 2030 erforderlich. In den 2030er Jahren flacht der Bedarf ab (ca. 1 Milliarde bis 2035 und nochmals 700 Millionen Euro bis 2040). Da der E-Mobility Markthochlauf derzeit dem zugrundeliegenden Transition Mobility Szenario hinterherhinkt, ist die für 2025 prognostizierte Nachfrage wahrscheinlich überschätzt. Daher wird die Wachstumsrate in späteren Jahren entsprechend steiler sein müssen. Abhängig davon, wie schnell der Markthochlauf den Zielpfad erreichen wird, kann es zu einer zeitlichen Kostenverschiebung von den 2020er auf die 2030er Jahre kommen. Der Großteil der Gesamtkosten mit durchschnittlich ca. **79 %** entfällt auf die Errichtung der **öffentlichen Ladeinfrastruktur für E-Pkw und leichte Nutzfahrzeuge**. Den Hauptfaktor dabei nimmt mit 66 % der Gesamtkosten die benötigte hohe Anzahl an öffentlichen Ladepunkten für Gelegenheitsladen / Destination Charging bei Einkaufs- und Freizeitzielen sowie auf öffentlichen Parkplätzen im städtischen Straßenraum. Hochleistungs-Schnellladeinfrastruktur für Pkw und leichte Nutzfahrzeuge macht durchschnittlich 13 % der Gesamtkosten aus. Weitere **21 %** der Kosten entfallen auf die **Infrastruktur für den Schwerverkehr** (öffentliche Ladepunkte und H2-Stationen).

Evaluierung des Bedarfs für öffentliche Fördermaßnahmen

Derzeit gibt es ca. 15 000 öffentlich zugängliche Ladepunkte in Österreich (etwa 14 300 Destinationen und 700 Range Extension Ladepunkte gemäß der GREENROAD Use Case Definition). Die Ergebnisse zeigen, dass bis 2040 insgesamt ca. 113 000 öffentliche Ladepunkte für E-Pkw und leichte Nutzfahrzeuge benötigt werden (davon ca. 109 000 Destination und 4 000 Range Extension Ladepunkte). Um diese Zahlen zu erreichen, ergeben sich ausgehend von 2022 notwendige Ausbaufaktoren von **4.9** (2030) und **7.6** (2040) für **Destination Charging** bzw. **5.4** (2030) und **5.6** (2040) für **Range Extension Charging**. Um die erforderliche Ausbaugeschwindigkeit beurteilen zu können, wurde ein Vergleich mit dem in den letzten 2 Jahren erfolgten Ausbau vorgenommen. Für den Use Case **Destination Charging** wurden zwischen Anfang 2021 und Anfang 2023 durchschnittlich ca. 3 200 zusätzliche Ladepunkte pro Jahr errichtet. Diese **Ausbaugeschwindigkeit** müsste **auf 7 000 Ladepunkte pro Jahr mehr als verdoppelt werden,** um den prognostizierten Bedarf für 2030 zu erreichen. Zwischen 2030 und 2040 genügen dann ca. 3 900 Ladepunkte pro Jahr. Für den Use Case **Range Extension** lag die Ausbaugeschwindigkeit zwischen Anfang 2021 und Anfang 2023 bei ca. 500 neuen Ladepunkten pro Jahr. National betrachtet wäre bis 2030 ein Zuwachs von ca. **400 neuen Hochleistungsladepunkten pro Jahr ausreichend,** wobei allerdings auch das Erreichen der erforderlichen geographischen

Abdeckung zu berücksichtigen ist. Zwischen 2030 und 2040 genügen aufgrund des eintretenden Sättigungseffekts im Durchschnitt etwa 10 neue Hochleistungsladepunkte pro Jahr. Für den Schwerverkehr wurde keine Gap-Analyse durchgeführt, weil derzeit de facto keine Ladestationen vorhanden sind. Die generellen Aussagen gelten analog für die Schwerverkehrsinfrastruktur. Ohne Förderung ist schwer zu erwarten, dass Akteure am Markt das ökonomische Risiko tragen werden wollen, die Ladeinfrastruktur im erforderlichen Ausmaß auszubauen, eine flächendeckende Versorgung sicherzustellen und dafür zu sorgen, dass die Infrastruktur den notwendigen technischen Standards entspricht. Die Ergebnisse von GREENROAD zeigen einen **Bedarf für Förderungen, um den Markthochlauf zu beschleunigen und die Errichtung der Ladeinfrastruktur in der nötigen Geschwindigkeit zu unterstützen**.

Handlungsempfehlungen

Zusätzlich zum notwendigen Modal Shift entsprechend den Zielen des Mobilitätsmasterplans 2030 ist ein intensiver Ausbau erneuerbarer Energien in Österreich von zentraler Bedeutung für die Erreichung der Klimaneutralität im Verkehr. Die GREENROAD Ergebnisse zeigen einen erheblichen Ausbaubedarf der Zero Emission Lade- und Betankungsinfrastruktur, wobei es signifikante Unterschiede sowohl zwischen Use Cases als auch auf regionaler Ebene gibt. Basierend auf der prognostizierten Nachfrage werden in Österreich bis 2030 ca. 70 300 Destination- und 3 800 Hochleistungs-Ladepunkte benötigt; bis 2040 sind es 108 900 und 3 900. Ausgehend vom Stand 2022 betragen die erforderlichen Ausbaufaktoren 4.9 (2030) und 7.6 (2040) für Destination Charging bzw. 5.4 (2030) und 5.6 (2040) für Range Extension Charging. Im Schwerverkehrssektor werden für Lkw und (Reise-)Busse in Österreich 1 400 öffentliche Ladepunkte bis 2030 und 1 600 bis 2040 benötigt. Davon entfallen ca. 70 % auf sogenannte Overnight-Charger mit ca. 150 kW und 30 % auf Megawatt-Charger. Sowohl für den Leichtverkehr als auch für den Schwerverkehr ist die **Nachfragespitze für Hochleistungs-Schnellladen bereits in den 2030er Jahren** zu erwarten. Danach tritt ein Sättigungseffekt ein und die Nachfrage für Range Extension Laden bleibt bis 2040 und darüber hinaus relativ stabil. Daher ist es erforderlich, den **Großteil der benötigten Hochleistungs-Schnelladepunkte für Range Extension Laden bereits bis 2030 zu errichten**, um weitere Verzögerungen im Markthochlauf der E-Mobilität zu verhindern. Da der Markthochlauf im Bereich der elektrisch betriebenen Fahrzeuge derzeit dem zugrundeliegenden Transition Mobility Szenario hinterherhinkt, ist die für 2025 prognostizierte Nachfrage wahrscheinlich überschätzt. Daher wird die Wachstumsrate in späteren Jahren entsprechend steiler sein müssen. Unter Berücksichtigung dieses **dringenden Handlungsbedarfs** ist eine zentrale Schlussfolgerung der Studie, dass **finanzielle Förderungen für die Etablierung einer Zero-Emission-Infrastruktur notwendig** ist. Bereits während der Fertigstellung der vorliegenden Studie wurde mit dem Start des ENIN Förderprogramms Anfang 2023 dahingehend ein wichtiger Schritt umgesetzt.

In Bezug auf H2-Technologie zeigen die Ergebnisse einen Bedarf von ca. 70 öffentlichen H2-Stationen bis 2030 und 130 bis 2040. Da größere H2-Fahrzeugflotten voraussichtlich nicht vor 2030 auftreten werden und insbesondere „Pioniere“ und größere Frächter auch auf private Betankungsinfrastrukturen errichten werden, ist die **Dringlichkeit hinsichtlich einer H2-Infrastruktur derzeit nicht so hoch wie für die elektrische Ladeinfrastruktur**. Das Ziel ist hier, eine Basis-Versorgung im Einklang mit den Entwicklungszielen auf europäischer Ebene zu schaffen, insbesondere entlang der TEN-Achsen. Es wird dringend empfohlen, einheitliche technische Standards für die Errichtung von H2-Stationen zu entwickeln.

Generell ist festzuhalten, dass derzeit ein gewisser Mangel sowohl hinsichtlich der erforderlichen Expertise als auch der benötigten Arbeitskräfte für den Infrastrukturausbau gegeben ist. Um einen raschen Infrastrukturausbau zu unterstützen, sollten geeignete Ausbildungs- und Arbeitsmarktmaßnahmen umgesetzt werden.

1 INTODUCTION

1.1 Background to the study

The Austrian government has not only committed to meet the goals of climate neutrality by 2040 but aims also to establish Austria as a pioneer in climate protection within Europe. This goal is particularly ambitious for the mobility sector. Currently transport is responsible for a significant environmental impact. These include, in particular, the emission of greenhouse gases (GHGs), air pollutants and noise, but also soil sealing as well as fragmentation and segmentation of the landscape and habitats. Therefore, among many other measures, the decarbonisation of road traffic is of particular importance for the achievement of the energy and climate targets. At present there are substantial gaps in information about the requirements this will place on future infrastructure. These gaps are primarily addressed by the GREENROAD project.

With a growing market penetration of EV technology, the number of newly registered electric vehicles as well as the number of publicly accessible charging stations has been rising significantly during the last decade. In 2022, the number of 100.000 registered electric passenger cars has been reached with currently about 14.000 publicly accessible charging stations in operation. The share of electric vehicles among newly registered passenger cars in Austria is currently about 20 %. *[5]*

In contrast to combustion engine vehicles, energy supply for electric vehicles is often provided by home charging. For certain user groups, home charging can even represent the most significant share of energy supply. Major challenges are legal barriers and the demand for investments to provide essential charging infrastructure and equipment, especially in existing properties. However the discussion regarding condominium owners has already led to an announced regulatory amendment introducing the so-called “Right to plug” in the Austrian “Wohnungseigentumsgesetz” in early 2022. *[6] [9]*

Hydrogen fuel cell trucks and buses are currently being tested by potential users like carriers and public transport providers. With ranges and refuelling times similar to combustion engine vehicles, they are expected to be ready for mass use around 2030. At present, publicly accessible hydrogen fuelling stations are not very widespread with only 5 locations in Austria (Wien, Innsbruck, Asten, Graz und Wiener Neudorf). *[43] [63] [69]*

The R&D project Energy Roads *[1]* examined the feasibility of an electric road system (ERS) using an overhead line for dynamic charging of heavy vehicles. Even after detailed examination of all technical, legal, and organisational aspects, no factor could be identified to rule out the successful implementation and operation of such systems. However, a clear political commitment to a widespread roll out of a standardized infrastructure throughout Europe is the main prerequisite to make progress in the development. For potential users and vehicle manufacturers the technology will only be of interest with a certain prospect of a growing network along the TEN-T corridors.

At present, intensive research is done on alternative fuels and e-fuels primarily for the use as Sustainable Aviation Fuels (SAF) und Sustainable Marine Fuels (SMF). The production of synthetic fuels is associated with high conversion losses while the use does not enable locally emission-free mobility. Therefore e-fuels are not considered as a sustainable solution in road traffic and will not be examined in the present study. *[64]*

1.2 Project goals

Building on the knowledge of preliminary studies, GREENROAD uses a top-down approach which implies that by 2040 100 % of road traffic in Austria must be powered by renewable energy. While for passenger cars and light commercial vehicles battery electric propulsion emerged as the unquestioned state of the art, fuel cell electric vehicles are considered in addition to battery electric vehicles for heavy duty vehicles.

Considering all road-based vehicle types, the study’s main objectives are:

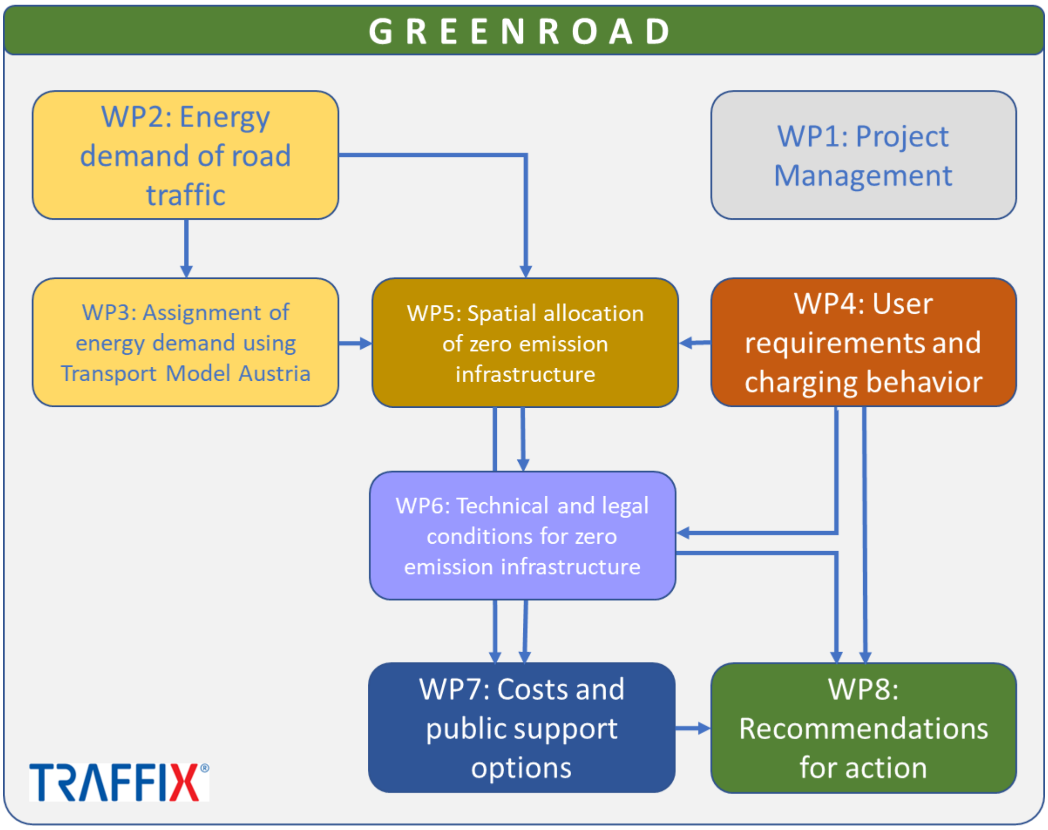
- to **provide a national quantity structure** and **detailed spatial allocation for the projected requirements of zero emission infrastructure** (charging points and H2 refuelling points) for the forecast years **2025, 2030, 2035 and 2040,**
- to **estimate the expected infrastructure costs,**
- to **evaluate the need for public support measures,**
- to **recommend necessary complementary actions** for the desired development and expansion of zero emission infrastructure.

The involvement of experts of all relevant industries as well as the careful consideration of the findings from current studies, projects and developments were of crucial significance.

1.3 Project structure

The project consists of 8 integrative work packages. Figure 1-1 shows the project structure and the content-related interaction of the work packages.

Figure 1-1: Project structure



Starting point of the research project was an analysis of future development of total road transport energy demand based on the energy scenarios of the Environment Agency Austria (WP2). *[26][27][28]*

In WP3 the National Traffic Model Austria (VMÖ) *[67]*, which is currently under development, was used to prepare the data and analyses required in for the projection model developed in WP5.

WP4 focussed on user requirements and charging behaviour, based on desk research, related previous projects and especially on a stakeholder engagement process. The comprehensive involvement of relevant stakeholders was of great importance for the success of the project. Figure 1-2 gives an overview of the cooperation partners involved by means of LoI.

Figure 1-2: Cooperation partners

In WP5, a specific calculation model for projecting the spatially allocated need for zero emission charging and refuelling infrastructure has been developed and applied. Thus, the required infrastructure development has been determined for the forecast years 2025, 2030, 2035 and 2040 on a national level as well as spatially allocated by municipalities and federal state respectively by motorway sections.

Based on the stakeholder integration and a literature research WP6 tackled challenges, difficulties and bottlenecks for the development of zero emission infrastructure considering technical as well as legal aspects. The infrastructure development costs were examined in WP7, along with the discussion of options for public policies and measures to support the desired large-scale development of zero emission infrastructure. Conclusively, summarized recommendations for action to accelerate the successful development of the zero emission infrastructure were derived in WP8.

1.4 Stakeholder Workshops

A stakeholder process has been initiated by consulting experts from different domains, forming following tentative focus groups:

- Focus group 1 “Zero emission policy in the transport sector”,
  10.10.2022; 13:00 – 17:00 h
- Focus group 2: “Charge point operators and technology”,
  17.10.2022; 13:00 – 17:00 h
- Focus group 3: “Users, usage behaviour and requirements”,
  18.10.2022; 09:00 – 13:00 h

The workshops were held as hybrid events and the invited stakeholders were free to choose whether to participate in person or online.

The focus groups discussed and supplemented the specifications of the various charging concepts as well as the user requirements/behaviours in order to collect important fields of action and challenges in the implementation of cero emission mobility. Scenarios up to the time horizon 2040 were discussed. In this context, also new technical developments and trends are discussed in the course of the workshops and their future potential is assessed. Participation in the workshops was pleasingly good and stakeholders actively contributed their experiences.

The presentation of the contents and documentation of the workshops was done with the help of the online collaboration platform Miro. All participants were able to actively read and comment on the recorded statements. In the appendix, the individual stakeholder workshop documentations are made available as deliverables. The workshop findings and collections of fields of action are of great value for the project and will be incorporated into further project work.

2 PROJECTED ROAD TRAFFIC ENERGY DEMAND

2.1 Background and methodical approach

The political mandate to emphasize the 2030, 2040 and 2050 energy and climate targets is set on all political levels:

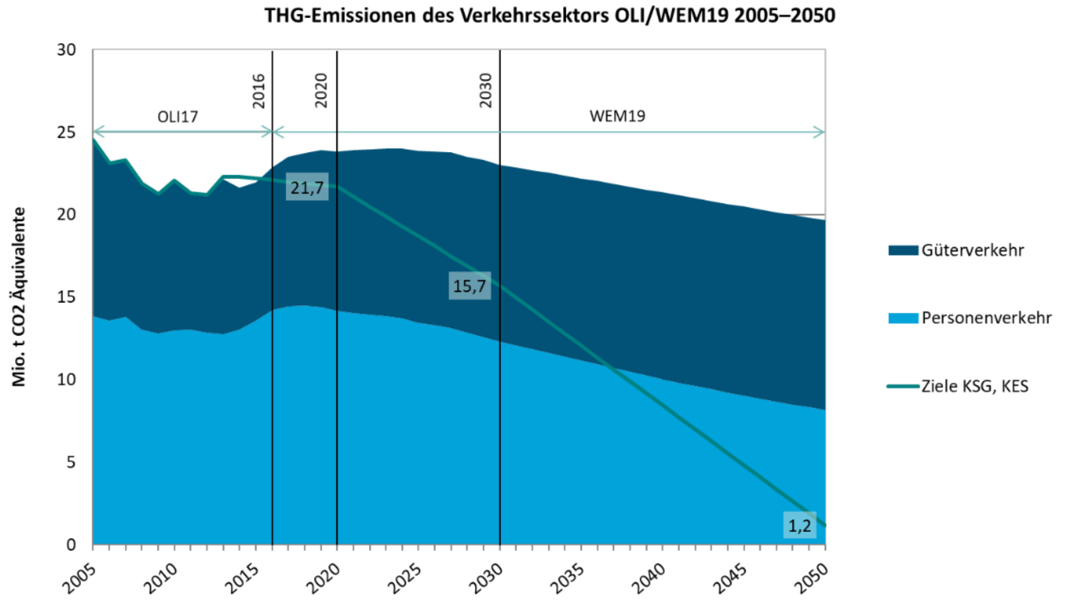
- Global perspective in the 2°C target in 2050 | UNFCCC *[65]*
- European perspective in the EU climate roadmap until 2050, the European Climate and Energy Package 2030 and the Revision of EU emissions trading system from 2020 *[39]*
- National government programme 2020-2024, national perspective in the Climate Protection Act Austria, the Energy efficiency law Austria and the Austrian 2030 Mobility Master Plan *[4]*

In its present form, the transport sector has a significant environmental impact, which in particular includes the emission of greenhouse gases (GHG), air pollutants and noise, but also soil sealing as well as fragmentation and segmentation of landscapes and habitats. Therefore, the transport sector is of exceptional importance for the achievement of the energy and climate targets.

Because of that, the Environment Agency Austria (Umweltbundesamt) is modelling different energy and climate scenarios. The greenhouse gas emissions from transport amounted to 22.9 million tons of CO_2-equivalents in 2016, making traffic the second largest polluter. Thereof 14.2 million tons are caused by passenger transport and 8.7 million tons by freight transport. As shown in Figure 2-1, the scenario with existing measures ("WEM19"), Austria's energy and climate targets will not be achieved.

In addition, the trend of emissions in the transport sector is highly problematic: they have increased by 67 % since 1990 and are particularly hindering the achievement of targets. The "#mission2030" and the national government programme 2020-2024 therefore emphasize that decisive action must be taken, especially in the area of transport, as it offers great savings and reduction potentials. Therefore the Environment Agency Austria (Umweltbundesamt) is currently working on an energy scenario in the mobility sector in order to achieve climate neutrality up to the year 2040.

Figure 2-1: Development of GHG emissions for passenger and freight transport in scenario WEM19 and targets until 2050



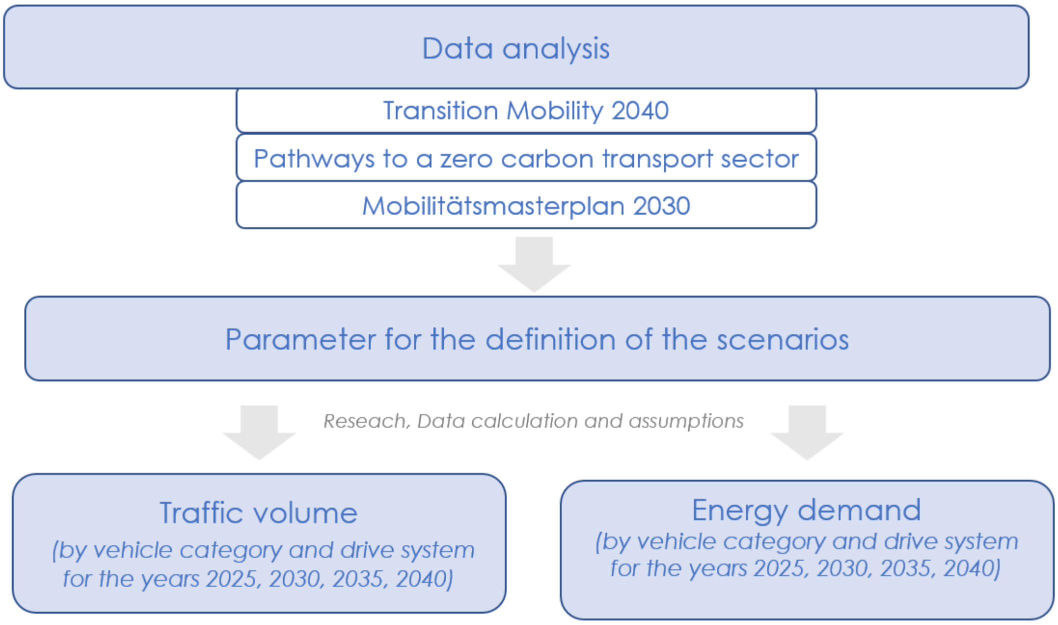
Quelle: 2005 - 2016: Ergebnisse der Österreichischen Luftschadstoffinventur (OLI2017)
2017 - 2050: WEM19

The development of road transport is analysed within different data structures of the Environment Agency Austria, also using data of the Austrian Air Pollutant Inventory (OLI, Umweltbundesamt).

In the previous R&D study "**Pathways to a zero carbon transport sector**" conducted by Umweltbundesamt *[27]* possible pathways to achieving the 2030/2050 climate goals for CO_2-neutral passenger and freight mobility have been identified. By application of scenarios, a mix of technology options in the transport sector and the use of alternative fuels and renewable electricity (e.g. ERS, battery-electric vehicles, fuel cells hydrogen vehicles) have been modelled, resulting in clearly communicable energy and technology pathways up to 2050. Simultaneously there is a cross-sectoral analysis including an estimation of its impact on the energy sector.

For the purpose of the present study, the total energy demand of road traffic in Austria (including passenger cars, light commercial vehicles, heavy goods vehicles and buses) from 2020 up to 2040 has been calculated within the energy scenarios of the Environment Agency Austria (**Transition Mobility 2040**) *[28]* and considering the scope of the Austrian 2030 Mobility Masterplan *[4]*. The results are presented in chapter 2.2.

Figure 2-2: Methodical approach for deriving the GREENROAD total energy demand



For the further use in the subsequent modelling steps, the GREENROAD energy scenario has been derived, which achieves zero emission mobility by 2040 and guarantees a balanced energy supply on a national level. This scenario specifies the future energy demand and the corresponding overall traffic performance (vehicle-kilometres) differentiated by vehicle categories and propulsion systems. The mix of alternative propulsion systems (e.g. battery-electric and hydrogen-based propulsions, electric road systems) and technology options within the different vehicle categories allows specific calculations of the energy demand. Within GREENROAD, the following differentiations are considered:

Vehicle categories

- Bikes and motorcycles
    - 2-stroke and 4-stroke motorcycle
    - Moped
    - E-Bike
    - E-Scooter
- Cars
- Light commercial vehicles (LCV)
- Heavy duty vehicles (HDV)
    - Solo truck < 18 t
    - Solo truck > 18 t
    - Semitrailer
    - Bus
    - Coach

Propulsion systems

- Electric systems
    - Battery electric propulsion systems (BEV)
    - Electric roads systems (ERS)
- Hydrogen fuel cell propulsion
- Fuels
    - Gasoline
    - Diesel

2.2 Energy demand of road traffic 2020-2040

Based on the underlying data sources and scenarios (see chapter 2.1), the GREENROAD road traffic energy scenario has been developed for further use in the subsequent modelling steps. The following chapters provide an overview of the overall energy demand of the road traffic sector, the energy demand by vehicle category and propulsion system and of the corresponding traffic performance in vehicle-kilometres.

2.2.1 Overall energy demand of road traffic sector

The GREENROAD project aims to develop a scenario for the road-transport sector to achieve the 2040 climate goals. An optimal mix in favour of alternative propulsion systems on renewable energies (electricity, hydrogen) has been developed for the transport sector. Thereby, a limiting factor is the amount of available renewable energy quantities (wind, water and solar energy as well as biomass).

A reduction of around 66 % in final energy consumption can be achieved by 2040 thanks to the desired propulsion mix and the assumed energy efficiencies and degrees of efficiency in the scenario. The amount of energy for road traffic will decrease from currently 249 PJ to around 84 PJ in 2040. In addition to the final energy consumption (kinetic energy), the required amount of primary energy must also be considered. This is defined as energy originating from natural energy sources that have not yet been processed further (e.g. oil, biomass, other renewables). From this, the available final energy consumption results from transport and conversion losses.

The following figures show the development of the energy amount of alternative propulsion systems and conventional fossil fuels in the period from 2020 to 2040. According to this, the use of fossil fuels will fade out until 2040. Regarding to alternative propulsion systems there is a steep increase in battery-electric and hydrogen fuel cell technologies.

Table 2-1: Energy demand of road transport sector 2020-2040

	Gasoline [PJ]	Diesel [PJ]	EV [PJ]	H2 [PJ]	Total [PJ]
2020	59	189	1	0	**249**
2025	46	131	17	0	**194**
2030	25	63	48	1	**137**
2035	7	15	74	3	**98**
2040	0	0	79	5	**84**

Figure 2-3: Fossil energy consumption in road transport sector 2020-2040

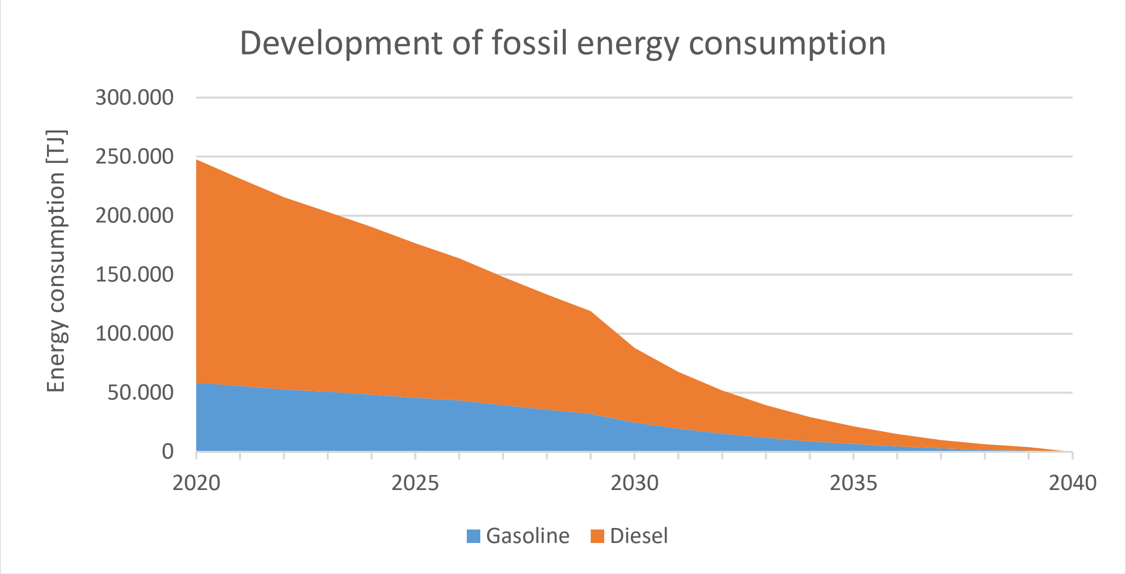
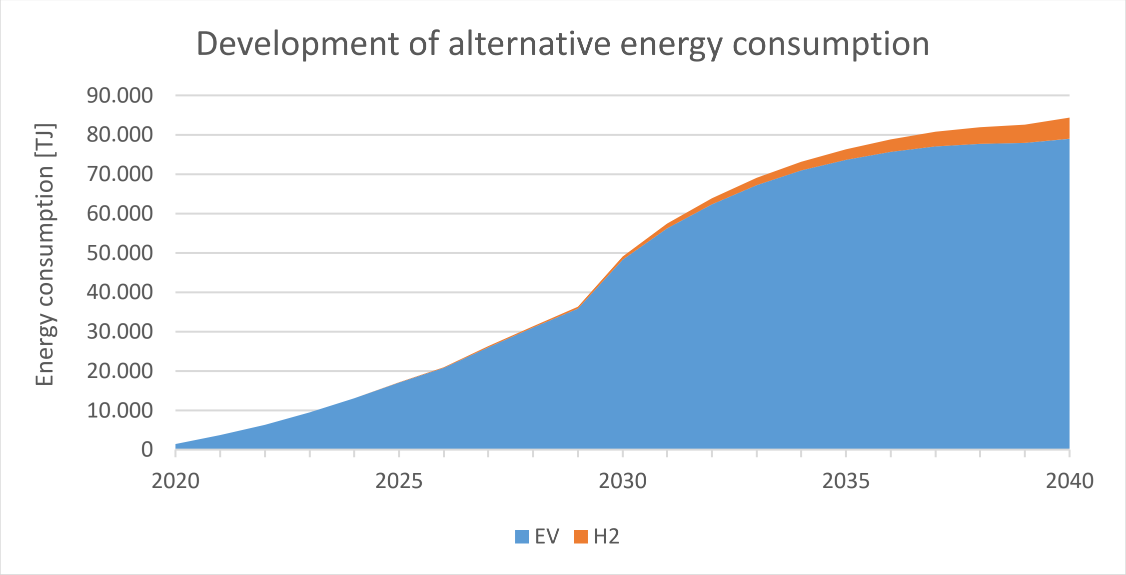


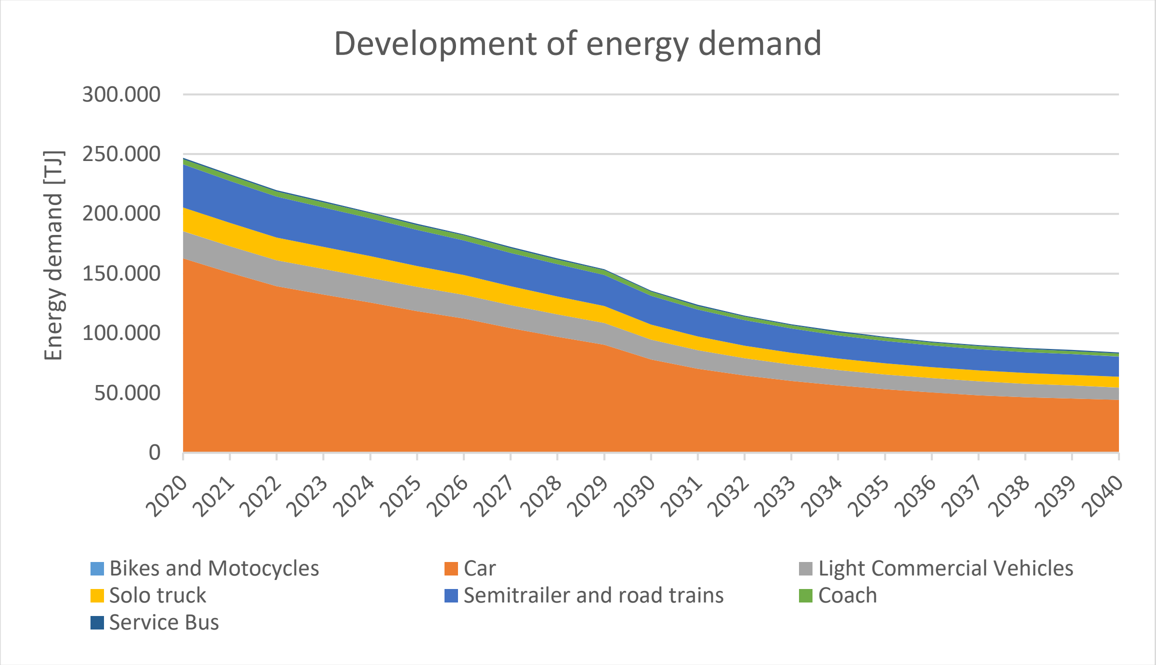
Figure 2-4: Alternative energy consumption in road transport sector 2020-2040



2.2.2 Energy demand by vehicle category and propulsion system

In 2040 passenger cars and light commercial vehicles will be predominantly battery-electric. Compared to synthetic fuels, the battery system has a very high level of efficiency, which means that motorized private transport can be completely defossilized and decarbonized. In the heavy-duty sector, a combination of and parallel infrastructure for battery-electric propulsions and hydrogen technology will be used, potentially complemented by electric road systems. For the bus sector it is assumed that buses in public transport will be operated by electric propulsion, while coaches will also use hydrogen fuel cell technology.

Figure 2-5: Total energy demand in road transport sector 2020-2040



The following tables show a comparison of the energy amount of alternative propulsion systems and conventional fossil fuels between 2020 and 2040. While 248 PJ fossil fuel is used in 2020, no more fossil fuels will be used in 2040. In 2040, 84 PJ of energy demand is zero emission 79 PJ battery-electric and 5 PJ fuel cell technology.

Table 2-2: Energy amount by vehicle category and propulsion system 2020

Energy amount 2020 [PJ]		Gasoline	Diesel	EV	H2	Total
Bikes and motorcycles		2	0	0	0	0
Cars		55	106	1	0	0
Light commercial vehicles		1	22	0	0	0
Heavy duty vehicles	Truck < 18 t	0	9	0	0	0
	Truck > 18 T	0	11	0	0	0
	Semitrailer	0	36	0	0	0
	Coach	0	4	0	0	0
	Service Bus	0	1	0	0	0
Total		**59**	**189**	**1**	**0**	**249**

Table 2-3: Energy amount by vehicle category and propulsion system 2040

Energy amount 2040 [PJ]		Gasoline	Diesel	EV	H2	Total
Bikes and motorcycles		0	0	1	0	1
Car		0	0	44	0	44
Light commercial vehicles		0	0	10	0	10
Heavy duty vehicles	Truck < 18 t	0	0	3	0	3
	Truck > 18 T	0	0	3	3	6
	Semitrailer	0	0	15	2	17
	Coach	0	0	2	1	2
	Service Bus	0	0	1	0	1
Total		**0**	**0**	**79**	**5**	**84**

2.2.3 Corresponding traffic performance by vehicle category and propulsion system

The development of the overall road traffic performance is correlated to the development of the total road traffic energy demand until 2040 as presented in chapter 2.2.2. According to the underlying Transition Mobility scenario, the overall traffic performance of road traffic will decrease from currently 87.96 billion vehicle-kilometres per year to 72.11 billion vkm in 2040. The scenario assumes a significant decline in passenger-kilometres in motorized private transport and no further increase of tonne-kilometres in road freight transport.

Figure 2-6: Traffic performance by vehicle category

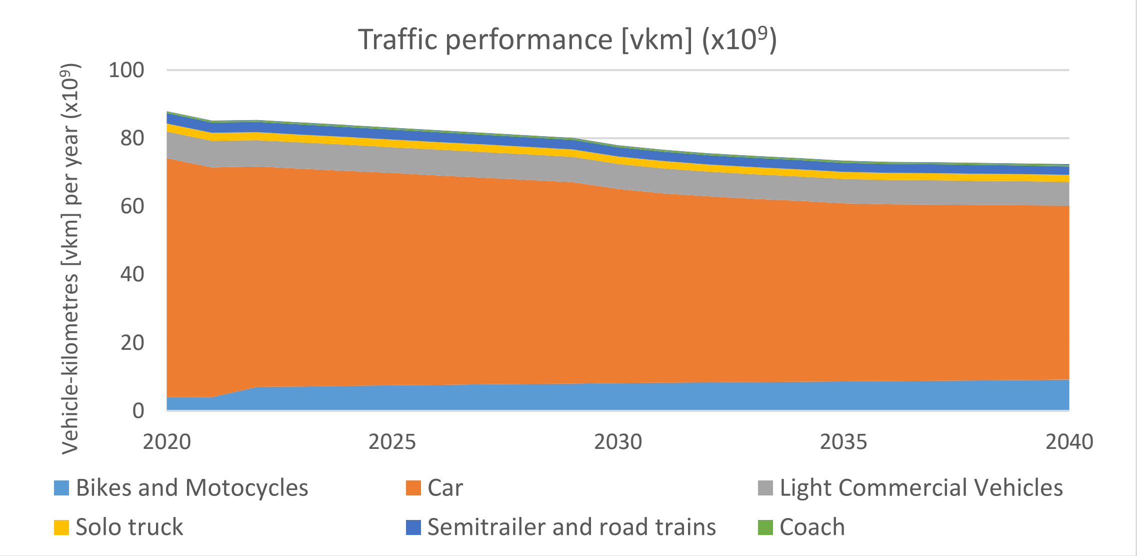


Table 2-4 and Table 2-5 show a comparison of the percentage shares of traffic performance by propulsion system and vehicle category for 2020 and 2040.

Table 2-4: Traffic performance by propulsion system 2020

Traffic performance [vkm] 2020		**Gasoline**	**Diesel**	**BEV**	**H2**
Bikes and motorcycle		98%	0%	2%	0%
Car		35%	63%	2%	0%
Light commercial vehicle		3%	96%	1%	0%
Heavy duty vehicles	Solo truck	0%	100%	0%	0%
	Semitrailer	0%	99%	1%	0%
	Coach	0%	100%	0%	0%
	Service bus	0%	88%	12%	0%

Table 2-5: Traffic performance by propulsion system 2040

Traffic performance [vkm] 2040		**Gasoline**	**Diesel**	**BEV**	**H2**
Bikes and motorcycle		0%	0%	100%	0%
Car		0%	0%	100%	0%
Light commercial vehicles		0%	0%	100%	0%
Heavy duty vehicles	Solo truck	0%	0%	81%	19%
	Semitrailer	0%	0%	91%	9%
	Coach	0%	0%	50%	50%
	Service bus	0%	0%	100%	0%

3 NETWORK ASSIGNMENT AND PREPARATION OF TRAFFIC MODEL DATA

Based on the projected energy demand and corresponding traffic performance presented in chapter 2, the road network model of the Austrian National Transport Model (VMÖ) was used to perform a route assignment to the road network.

3.1 Overview of the Austrian National Traffic Model

The Traffic Model Austria ("VMÖ") *[67]*, which is currently under development, is funded by the Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK), ASFINAG and ÖBB Infra. The model has its base year in 2018 and will subsequently provide the forecast horizons 2025, 2030, 2035, 2040 and 2050. The VMÖ multimodal network model provides a detailed picture of the Austrian road and rail network and therefore is a profound basis for modelling the spatial allocation of zero emission road traffic infrastructure conducted in GREENROAD. Below, some key features of the VMÖ are summarized.

Figure 3-1: National Traffic Model VMÖ

Key features of the VMÖ

- Multimodal transport model for entire Austria (incl. Europe-wide projection of international origin, destination and through traffic)
- Spatially high-resolution socio-economic data (population by socio-demographic characteristics, household income, car ownership, workplaces and employees, tourist arrivals and nights spent, points of interest etc.)
- High-resolution routable multimodal network model (road, rail, public transport, waterway)

- Subdivision of the model area into approx. 6 500 zones (very detailed zoning within Austria, zone sizes enlarged by distance)
- Passenger transport demand model (based on empirical mobility surveys such as *Österreich Unterwegs* and additional stated preference surveys):
    - Traffic generation: Tour-based modelling of trip generation, differentiated by activities such as work, education, shopping, leisure, etc.
    - Modelling of choice of destination
    - Modelling of mode choice (modal split), differentiation of the means of transport (car driver, car passenger, public transport, bicycle, walking)
    - Modelling of the departure time (7 time slices)
    - Comprehensive consideration of socio-economic characteristics (modelling of synthetic population)
    - Assignment of traffic flows to the network model
    - Modules for Park & Ride and Car sharing
- Freight transport demand model
    - Detailed modelling of freight transport demand using a multi-level multimodal choice model (based on empirical freight transport surveys and stated preference surveys)
    - Consideration of the modes of transport road (truck/semitrailer, solo truck, light commercial vehicle), rail and waterway
- Upstream economic model (international trade and freight flows)
- Modelling of the annual average working day and the annual average weekday and additional differentiation according to 7 time slices (e.g. morning peak, mid-day, evening peak etc.)
- Model validation and calibration for the base year 2018 taking into account numerous empirical data bases (in particular traffic counts of ASFINAG and the provinces, public transport passenger counts, commuter statistics and nationwide special evaluation of passenger flows based on mobile phone data)
- Integrative traffic forecast for different scenarios and horizons up to 2040 and 2050
- Evaluation options (among others):
    - High-resolution spatial-structural data (approx. 6500 zones)
    - Traffic volume and traffic performance by mode or means of transport
    - Modal split
    - Traffic volume per road section differentiated by vehicle type and time slices
    - Differentiation of traffic volume per road section by purpose (work, education, shopping, leisure etc.) and trip distance
    - Spider evaluations per road section with detailed source-destination relationships of traffic demand
    - Detailed spatial/temporal differentiations

Although the VMÖ is currently under development, already available derivates (especially concerning the road network model and preliminary base year demand matrices) could be used for the purposes of the GREENROAD study.

3.2 Preparation of traffic demand forecast matrices

In order to be able to perform the network assignment of traffic volumes, the projected overall traffic performance and energy demand presented in chapter 2 were deployed into the VMÖ model structure and linked with the preliminary base year matrices for each vehicle category. For the forecast years the estimated development of spatial structural data like inhabitants and employees per zone were considered in alignment with the current scenario development process of the VMÖ *[67]*. Therefore, origin-destination-specific extrapolation factors were derived to consider the projected structural developments per zone (mainly regarding the number of inhabitants and employees) for the periods to 2025, 2030, 2035 and 2040. These factors were applied to the preliminary VMÖ base year demand matrices using the so-called Multi-Procedure by Lohse *[17]*, which is a double-linked projection method implemented in the VISUM software package.

Table 3-1: Derivation of OD-specific demand projection factors

Vehicle category	**Projection factors derived based on …**
Car	Weighted development of **inhabitants** and **employees** per zone
LCV	Development of **employees** in primary, secondary and specific fields of tertiary sector per zones
Solo-Truck	Development of **employees** in primary and secondary sector per zone
Semitrailer	Development of **employees** in primary and secondary sector per zone

By scaling the matrices to the total sums provided by the Environment Agency Austria, the outcomes were traffic demand matrices for 2025, 2030, 2035 and 2040 (number of trips per workday by vehicle category) that represent the overall traffic and energy demand according to the underlying scenario (see chapter 2) and at the same time enable a high spatial resolution according to the VMÖ model structure with approx. 6500 zones.

3.3 Assignment to road network

For the network assignment of the projected traffic demand matrices, the road network model of the VMÖ *[67]* has been used as a basis. In addition, already determinated measures for the horizons 2025, 2030, 2035 and 2040 on the highway network have been considered and implemented into the network model. Table 3-2 gives an overview of the measures taken into account.

Table 3-2: Considered highway network expansion measures from 2018 to 2040

Highway	**Measure**	**Expected finalization**
A5 Nord Autobahn	Construction Drasenhofen Süd – Drasenhofen Nord	2019
S3 Weinviertler Schnellstraße	Construction Hollabrunn Süd – Hollabrunn Nord	2019
S3 Weinviertler Schnellstraße	Construction Hollabrunn Nord - Guntersdorf	2020
A4 Ost Autobahn	Third lane Fischamend – Bruck/Leitha West	2022
A14 Rheintal/Walgau Autobahn	New connection point Dornbirn Süd	2022
S7 Fürstenfelder Schnellstraße	Complete construction	2024
A26 Linzer Autobahn	Construction bridge Donaubrücke (1 lane)	2024
A11 Karawanken Autobahn	Construction second tunnel tube Karawank-entunnel and blockade of first tunnel tube	2025
A11 Karawanken Autobahn	Reopening of first tunnel tube Karawankentunnel	2027
S10 Mühlviertler Schnellstraße	Construction Freistadt Nord – Rainbach Nord	2027
A26 Linzer Autobahn	Construction of tunnel Freinberg, opening of 2 lanes on bridge Donaubrücke	2029
A26 Linzer Autobahn	Reconstruction of bridge Westbrücke	2031

Sources: *[33] [37]*

The following figures show exemplary illustrations of traffic flows as a result of the assignment of traffic demand matrices to the road network.

Figure 3-2: Traffic assignment Car 2040 | Exemplary illustration Vienna region

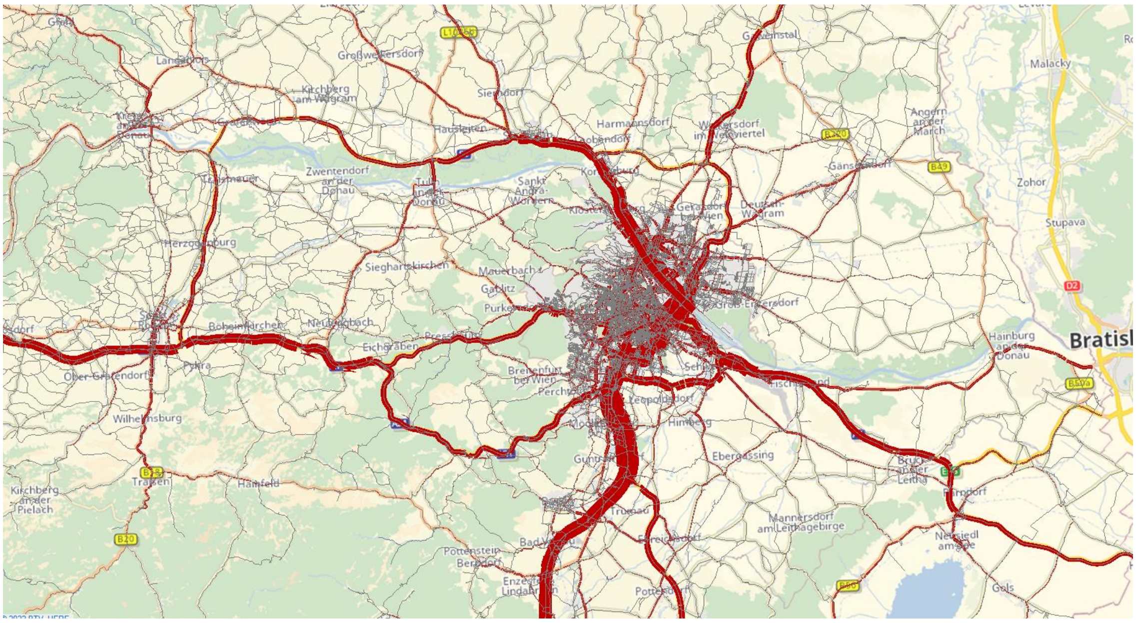


Figure 3-3: Traffic assignment LCV 2040 | Exemplary illustration area Graz – Klagenfurt

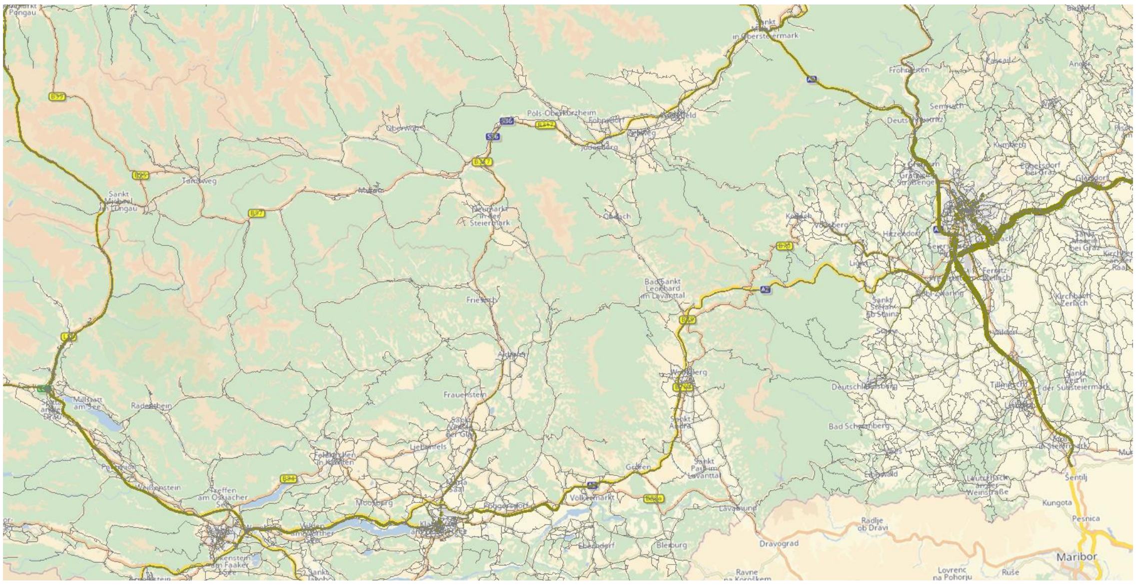
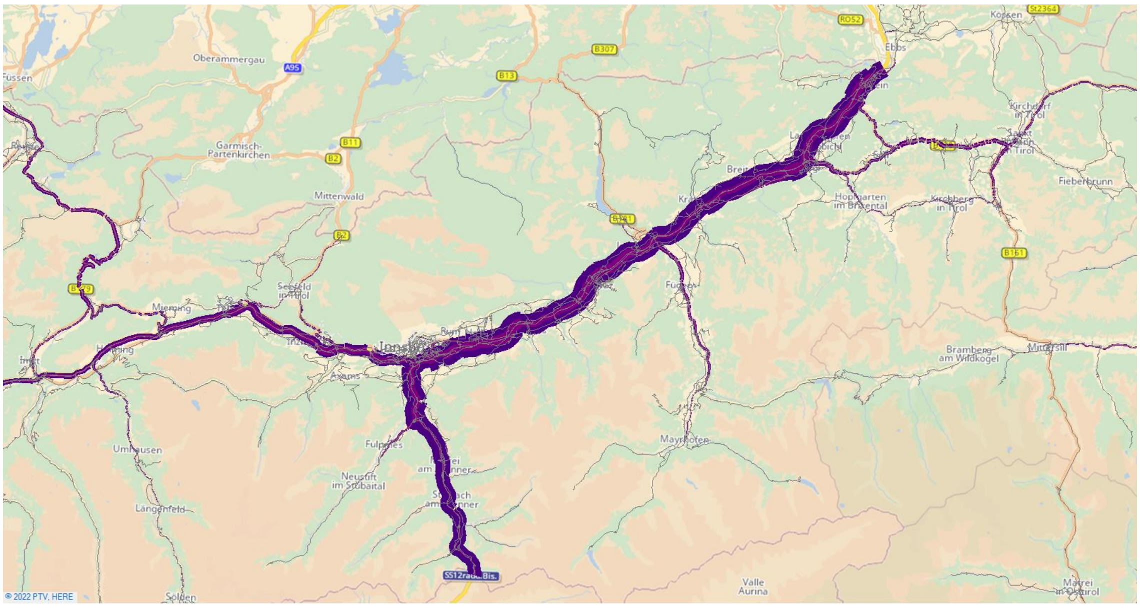


Figure 3-4: Traffic assignment HGV 2040 | Exemplary illustration area Unterinntal – Brenner



For the purpose of the spatially allocated demand forecast for zero emission road infrastructure as presented in chapter 5, it is necessary to consider adequate differentiations of traffic demand regarding the need for publicly accessible charging or H2 refuelling. Obviously, on the one hand it is required to consider different trip distance classes, as longer trips have a higher probability of need for publicly accessible charging compared to short trips). On the other hand it is important to differentiate between spatial types, as in rural areas the possibilities for private home charging tend to be higher than in urban areas. While operating on OD-matrix level, 3 spatial relation types were defined: trips from urban to urban areas, trips from rural to rural areas and trips from rural to urban areas v.v. For this purpose, the spatial types included in the VMÖ data structure were used. Considering these aspects, the traffic demand matrices and the corresponding network assignment results have been segmented into overall 48 demand segments (4 vehicle categories, 3 spatial relation types and 4 distance classes, see Table 3-3).

Whereas the traffic network assignment is mostly relevant for the use case range extension charging, the use case destination charging follows a different pattern, as the attractivity of destination zones is most important here (for details refer to chapter 5). Therefore, demand data on OD-level has been prepared segmented by 4 trip purposes (number of starting and ending trips per zone by trip purpose). Additionally combined with structural data (population, households, car fleet, employees and purpose-specific points of interest) these datasets were used for modelling the spatial allocation of destination charging infrastructure (see chapter 5). Table 3-4 gives an overview of the considered trip purposes and structural data information.

Table 3-3: Demand segments differentiated in network assignment

Dseg no.	Vehicle category	Spatial relation type (SRT)	Trip distance class
1	Car	urban – urban	< 50 km
2			50 – 100 km
3			100 – 300 km
4			> 300 km
5		rural – rural	< 50 km
6			50 – 100 km
7			100 – 300 km
8			> 300 km
9		rural – urban v.v.	< 50 km
10			50 – 100 km
11			100 – 300 km
12			> 300 km
13	Light commercial vehicle (LCV)	urban – urban	< 50 km
14			50 – 100 km
15			100 – 300 km
16			> 300 km
17		rural – rural	< 50 km
18			50 – 100 km
19			100 – 300 km
20			> 300 km
21		rural – urban v.v.	< 50 km
22			50 – 100 km
23			100 – 300 km
24			> 300 km
25	Solo truck	urban – urban	< 50 km
26			50 – 100 km
27			100 – 300 km
28			> 300 km
29		rural – rural	< 50 km
30			50 – 100 km
31			100 – 300 km
32			> 300 km
33		rural – urban v.v.	< 50 km
34			50 – 100 km
35			100 – 300 km
36			> 300 km
37	Semitrailer	urban – urban	< 50 km
38			50 – 100 km
39			100 – 300 km
40			> 300 km
41		rural – rural	< 50 km
42			50 – 100 km
43			100 – 300 km
44			> 300 km
45		rural – urban v.v.	< 50 km
46			50 – 100 km
47			100 – 300 km
48			> 300 km

Table 3-4: Demand segments differentiated on OD-matrix level and structural data

Vehicle category	Data type	Dataset
Car	Traffic demand per zone	Number of destination trips | Trip purpose Work
		Number of destination trips | Trip purpose Shopping
		Number of destination trips | Trip purpose Leisure
		Number of destination trips | Trip purpose Other
	Structural data per zone	Population (inhabitants)
		Households
		(E-)Car-fleet
		Employees
		Weighted points of interest | Shopping
		Weighted points of interest | Leisure
LCV	Traffic demand per zone	Number of origin/destination trips
Solo truck	Traffic demand per zone	Number of origin/destination trips
Semitrailer	Traffic demand per zone	Number of origin/destination trips
	Structural data per zone	Intermodal terminals

The E-Car-fleet per zone has been projected using a combination of the overall private car fleet (respectively motorization rate) per zone according to VMÖ data and the scenarios provided by the Environment Agency Austria *[28]*. Specifically for semitrailers, in addition to the number of origin/destination trips per zone, the presence of intermodal terminals has been considered in order to emphasize the relevance of such locations as potential charging sites.

As for coaches there are no transport demand matrices available in the VMÖ model, the required data was calculated on a simplified basis using average shares of the overall traffic volumes on the road network derived by traffic counts. For buses of public transport a separate approach was done by considering the amount of starting and ending rides per zone (using the detailed schedules of public transport implemented in the VMÖ).

4 USER REQUIREMENTS AND CHARGING BEHAVIOUR

4.1 Evaluation of charging and refuelling concepts

The following chart gives an overview of state-of-the-art renewable road mobility technologies and their application for a range of use cases. The focus is put on energy flows, their efficiencies and the possibilities and practical considerations for users and stakeholders. An overview is given for different mobility needs regarding what type of vehicle can fulfil them. The different possibilities how these vehicles can be supplied with energy are described in the affiliated chapters below.

Table 4-1: Applicability of renewable charging technologies

	Bike	**Car**	**LCV**	**Bus**	**Solo truck**	**Semitrailer**
Commute to/from work-place/school	**Electric: a, b**	**Electric: a, b, (c)** **Hydrogen: a**	**Electric: (a), b, (c, d)** **Hydrogen: a, b**	**Electric: b, (c, d)** **Hydrogen: a, b** **Overhead: b**	-	-
Groceries/ Shopping	**Electric: a, c**	**Electric: a, c** **Hydrogen: a**	-	-	-	-
Business	**Electric: a, b, c**	**Electric: (a), b, c, d** **Hydrogen: a, b**	**Electric: (a), b, (c, d)** **Hydrogen: a, b**	-	**Electric: b, c, d** **Hydrogen: a, b**	-
Leisure, Travel	**Electric: a, b, c**	**Electric: a, c, d** **Hydrogen: a**	-	**Electric: b, d** **Hydrogen: a, b** **Overhead: a, b**	-	-
Transportation	**Electric: a, b, c**	-	**Electric: b, d** **Hydrogen: a, b**	-	**Electric: b, d** **Hydrogen: a, b** **Overhead: a, b**	**Electric: b, d** **Hydrogen: a, b** **Overhead: a, b**

4.1.1 Electric charging of vehicle battery

a. Home charging

Multiple possibilities of charging an electric vehicle via a private charging station are covered. The charging power ranges from up to 4.6 kW for single phase chargers, to 11 and 22 kW for three-phase grid connection chargers. Depending on charging technology and vehicle efficiency, between 0.2 and 2 km range per minute possible. *[31]* High speed home chargers reduce charging times significantly compared to slow charging, for instance at 5.5 kW. On the other side, fast charging, especially if a large amount of energy is charged at once, has a strong negative effect on vehicle battery life. *[7]* Cycle life of vehicle batteries is maximized with small changes in state-of-charge at around 50 %. Due to the long residence time, slow charging speeds and coordinated charging strategies are not significantly affecting customer needs. As typical daily driving distances are below 50 km, this capacity can be recharged within 2 hours at 5.5 kW charging power. By shifting charging times later into the night, peak energy demand of a household is significantly decreased in the evening. High power charging stations are generally more expensive and in some cases grid providers can restrict household connections which exceed 15 kW peak power demand. Bidirectional charging technologies are under development and show high potential to use vehicle battery capacity as electricity storage devices. *[7]*

b. Charging at the workplace

Comparable technology as home charging, with large number of charging points for staff vehicles, company vehicles, transporters and other mobility. High-power grid connections are already available for many businesses. Internal coordination to reduce grid impact and peak power loading. Company vehicles may also be charged during the night with slow charging speeds to reduce grid impact. Fast charging stations for range extension or special demands. Commuter vehicles are available to benefit from photovoltaic power production.

c. Publicly accessible / roadside charging

Publicly available charging stations on roadsides or public parking spaces. Mainly 11-22 kW for customers without own charging possibilities, shared vehicles and range extension. Also includes other charging possibilities for electric bikes.

d. Fast charging

Located at long distance traffic routes. Used for quickly recharging a share of the total capacity for range extension. Mainly high to very high (90 kW+) charging power for increased charging speed of 3-15 km range per minute for passenger vehicles. *[31]* For electric trucks, technologies with even higher power are being tested. 350 kW are already being introduced, > 900 kW (Megawatt Charging technology) under research. *[23]* For trucks this means an already available charging speed between 1.5-10 km/min, with Megawatt chargers proposed to reach 20-100 km/min range extension. High power charging stations need to be connected directly to higher grid levels, to support peak energy demand.

Mobility as a service

There is a strong shift in user behaviour to mobility as a service (MaaS) offers. This includes rideshare, rental or community owned modes of transport. In many cases, these modes have proprietary charging stations but may also use publicly accessible charging options. As users are more open to new concepts, the potential is far from being exhausted.

4.1.2 Hydrogen refuelling

a. Publicly accessible refuelling station

High refuelling speeds can be reached, with about 160 km/min for 350 bar and 220 km/min for 700 bar. Electrolytic production of hydrogen from water has an approximated efficiency of 55 %. The powertrain of a hydrogen fuel cell vehicle is operating on approximately 45 % efficiency, which is making the technology very energy intensive. The high energy demand makes the CO2 balance of this technology very sensitive to the source of primary energy. Renewable energy can be used for the production and storage on short term. Long term storage is not yet solved but feeding in depleted natural gas deposits shows very promising results. *[3]*

b. Proprietary refuelling station

Companies may operate exclusive hydrogen plants for their fleet, to profit from low electricity prices, use hydrogen production for other processes (steam, high temperature processes) and benefit from energy storage possibilities.

4.1.3 Electric Road Systems (ERS)

a. Overhead dynamic charging

This tested technology is working by charging battery-electric trucks using a cantilever (similar to electric train cantilever). 25-50 % of Austrian highway kilometres are suitable for overhead power lines. The most prominent technology is relying on a direct current (DC) energy supply with 1,2-1,5 kV Voltage. Parallel fast charging of battery and propulsion of electric motors. While connected to the overhead powerline, up to 8 km per minute additional range may be recharged in the battery. For overtaking manoeuvres, sections without powerline and for transit to and from highways, the cantilever is retracted, and the truck is powered by battery storage. Trucks going downhill can feed in recuperation energy directly into the electricity grid. Trucks going uphill can draw high power from the grid, to reduce battery requirements. Studies show that over 90 % of routes leaving highways are less than 100 km. *[1]* With modern electric trucks having ranges of up to 300 km, all applications are covered. *[23]*

b. Overhead stationary charging

Truck cantilevers used for highway-recharging may also be used for stationary charging with high power and reduced space requirements. Many trucks can be charged via the same charging inverter.

c. Dynamic charging concepts at road surface Level

There exist other concepts to electrify road infrastructure similar to overhead powerlines. The two most significant being inductive charging and power rails embedded in the road surface. Inductive charging is faced with low efficiency and high cost over the entire lifespan.

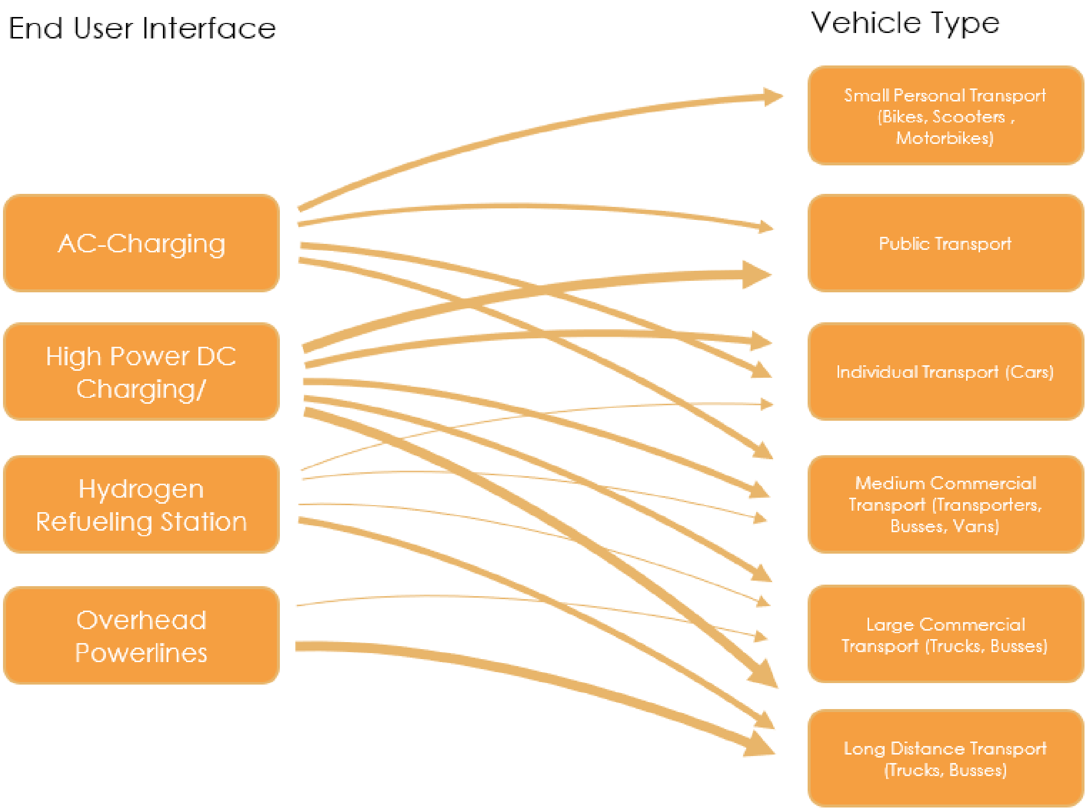
Ground conductive charging

Some studies suggest that ground conductive charging via a pickup-sled might be a significantly more economic option to overhead power lines. *[24]* It has the option to also support passenger vehicles. Above ground infrastructure requirements are lower than overhead power lines, which makes a large share of road sections eligible for electrification. Most of the advantages of overhead charging, can also be fulfilled by this option. *[47]* However, as there is not as much technological experience and some problems yet to be solved, it seems unlikely that a large-scale implementation will occur in the near future. Additional research should be put in this topic before a unified European standard is being decided.

4.2 Technical End-User Interfaces

Renewable Energy sources for road traffic uses, provide numerous possibilities to transfer energy to customers.

Figure 4-1: Vehicle Types and Energy Supply



Description: Energy Supply Technologies and applicable vehicle types. The significance of the technologies is indicated by arrow thickness.

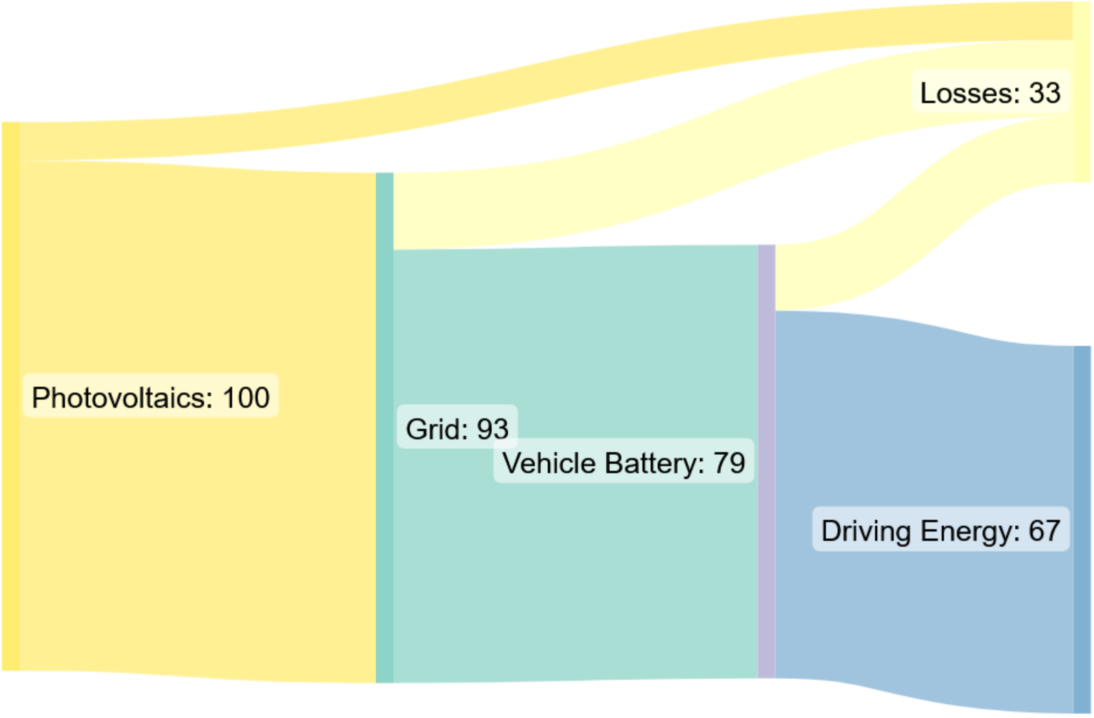
Most important for the short-term transition to renewable mobility are battery-electric vehicles (BEVs). Charging is conducted via alternating current (AC) and an onboard rectifier for small vehicles, or direct current (DC) charging for high power applications. For almost all technologies, high-power charging and battery-electric propulsion systems are being developed rapidly and are replacing conventional technologies. High charging power allows for faster recharging for smaller vehicles and are the only practical solution for large BEVs as trucks. High-capacity charging stations require a grid connection with adequate capacity, especially if more than one vehicle is charged at the same time. Energy losses during the charging process rise with charging power. This is accepted for range extension or publicly accessible charging, where there is a focus on short charging times.

Nowadays only a small number of publicly accessible hydrogen filling stations exists in Austria, which limits applications. For long distance transport, hydrogen might become an option within the next decades. Especially as hydrogen seems a promising technology to store renewable energy at this scale. Currently electric technologies are less cost-intensive and are more technologically advanced, which is making them the preferred choice among consumers and manufacturers. Overhead charging is especially interesting for long-range applications, as battery weights can be significantly reduced to reach the range requirements. For other commercial applications as Solo-Trucks and Buses, where most driving distances are covered by the battery capacity, the same overhead charging standards can be adapted as an automated, stationary recharging possibility, for range extension on highways and for coach buses.

4.3 Exemplary Energy Pathways

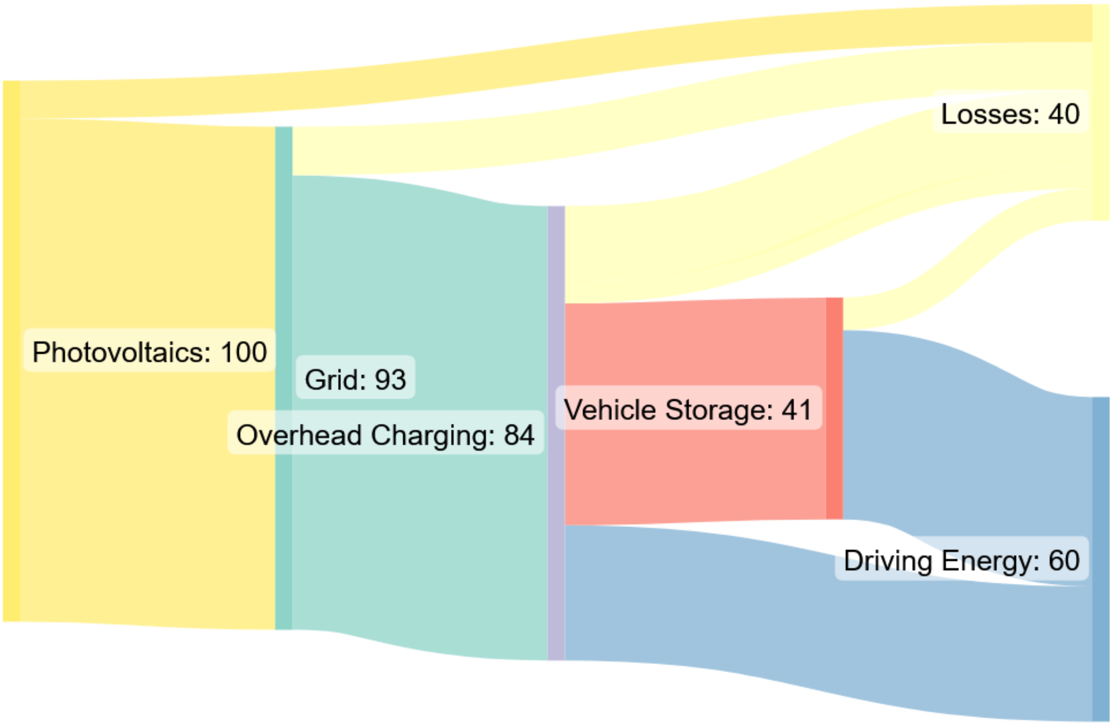
For better overview over the different technologies, Energy flow charts are shown. These only include the energy in kWh but make no statement about economic efficiency or power requirements. The energy flow starts at the source, here photovoltaics as a reference and ends at (kinetic) driving energy. For simplification, regenerative braking is not considered.

Figure 4-2: Energy-Flow for Battery-Electric Vehicles (Car)



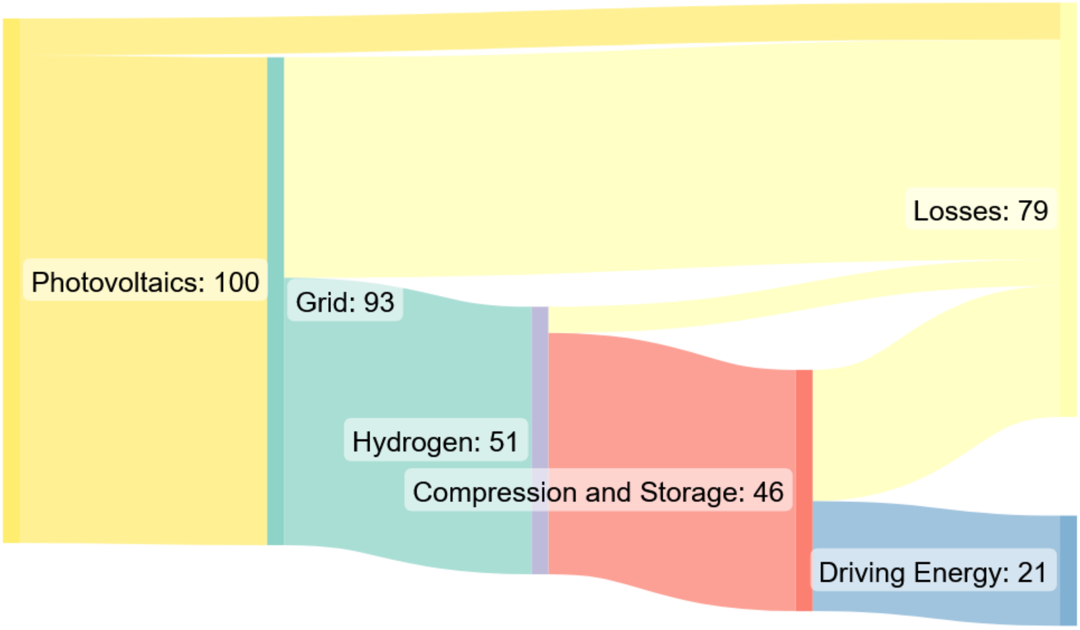
Description: Typical efficiencies of the energy conversions of a fully electric passenger vehicle. Efficiency factors: Grid 93%*[58]*, Battery charging (AC/DC) 85% *[16]*, Drivetrain Efficiency 85% *[30]*

Figure 4-3: Energy-Flow for Overhead charging of an electric truck



Description: An estimation for the energy efficiency of a highway system with about 25 % coverage with overhead powerlines is given. It is estimated that 1/3 of the energy requirements are directly fed by overhead powerlines on highways. The remaining 2/3 are supplied by the electric battery, which is also charged by overhead lines while driving or being stationary. An additional energy loss of 10 % for AC/DC Transformers and distribution at the powerline is estimated. Efficiencies: Grid 93% *[58]*, Overhead Powerline 90% *[32]*, Vehicle Charging 85% *[16]*, Drivetrain 85% *[30]*

Figure 4-4: Energy-Flow for a Fuel Cell Vehicle (Car)



Description: A hydrogen fuel station with on-site hydrogen production and compression is assumed. Here a proton exchange membrane fuel cell under real-life, worst case conditions and a refuelling pressure of 700 bar was chosen. Efficiencies: Grid 93% *[58]*, Electrolysis 55% *[16]*, Compression and Storage 90% *[16]*, Fuel cell and Drivetrain 45% *[10]*

From these visualizations it can be seen that electric drivetrains have a high energy efficiency compared to hydrogen fuel cell vehicles. Batteries of electric vehicles have a good return of energy, as battery technology and charging methods have improved significantly. Electrolysis and fuel cells are less efficient in real-life applications compared to laboratory settings, as additional energy demands are necessary. These include conditioning of the fuel cell to keep it in an optimal operating range, water treatment, hydrogen compression, losses during storage, losses during refuelling and losses to keep the fuel cell in an optimal working temperature. For battery electric vehicles energy demands for cooling and heating within the battery also occur during charging and recharging but can be managed more efficiently by applying appropriate design principles of the battery casing and air cooling. *[20]*

4.4 Suggested Applications

In the course of this literature review, following applications for the different technologies were found to be sensible:

- Light vehicles and bikes, with short daily distances and low power requirements should also in the future be powered by electric batteries. Low cost, high efficiency and high flexibility are the main drivers.
- Battery electric propulsion has by far surpassed fuel cell technologies, by being more technologically advanced and profiting from a significant economy of scale concerning battery cell production and electric motors. For all applications electric propulsion can be seen as the most promising technology, as a high level of performance, reliability at a relatively low price can be achieved. In almost all use cases, on-board batteries supply enough range for day-to-day use.
- Long distance transportation, including coaches, supplied by battery systems, either require a change in user behaviour by making more frequent stops for recharging or dynamic charging on the road, to achieve comparable range flexibilities as conventional technologies. Overhead dynamic charging seems promising, as there is high technological readiness and high efficiency compared to inductive charging. Conductive charging via ground rail seems to have a large potential for including all types of vehicles and promising economies of scale but is not yet developed enough to be a viable option. For dynamic charging systems to succeed, international standardization, is crucial. In the short-term, high-power charging stations and fully electric vehicles seem like the most reasonable path for long range transport.
- Hydrogen as a fuel seems most likely to be used for long range transportation, as increased battery weight and range make battery powered vehicles less efficient. As high refuelling speeds are possible, system costs may be compensated for many applications. Low overall energy efficiency can be accepted by using renewable electricity for green hydrogen production. Hydrogen refuelling stations can be placed along highways, at locations with large electric grid capacities and can be combined well with high power electric recharging stations.

4.5 Specification of parameters for calculation model

Work package 4 gathered a comprehensive knowledge base from a substantial literature review as well as from numerous experts and stakeholder organisations and provides a foundation for the discussion of various aspects related to the following modelling tasks. As a central input for the GREENROAD calculation model (refer to chapter 5) specific parameters for the considered vehicle categories have been defined (see Table 4-2). These parameters are mainly based on data sources related to the latest energy scenarios of the Environment Agency Austria (Transition Mobility 2040 *[28]*) and have been complemented by findings derived from a profound market and manufacturer research.

Table 4-2: Vehicle related parameters | Average vehicle capacity and range

Vehicle type	Average energy capacity [kWh]		Energy consumption [kWh/100 km]		Average vehicle range [km]	
	2025	**2040**	**2025**	**2040**	**2025**	**2040**
Car	60	100	20	20	300	500
LCV	80	120	40	40	200	300
Solo truck |E	400	800	110	110	364	727
Solo truck | H2	30 kg = 990 kWh	35 kg = 1155 kWh	191	172	518	672
Semitrailer | E	900	1200	155	155	581	774
Semitrailer | H2	50 kg = 1650 kWh	80 kg = 2640 kWh	262	236	630	1119
Coach | E	400	800	132	132	303	606
Coach | H2	35 kg = ca. 990 kWh	35 kg = ca. 1.155 kWh	210	189	471	611
Service Bus | E	400	800	150	150	267	533

Sources: Transition Mobility 2040 *[28]*, Market- and manufacturer research *[35] [36] [38] [44] [46] [53] [54] [55] [59] [66]*

5 FORECAST AND SPATIAL ALLOCATION OF REQUIRED ZERO EMISSION INFRASTRUCTURE

5.1 General methodical approach and description of the projection model

For the purpose of the present study, a specific calculation model for assuming the spatially allocated need for zero emission charging and refuelling infrastructure has been developed. This projection model is mainly based on the following input elements (more details are described in subsection 5.2):

Main model input elements

- projected **overall energy demand** and corresponding traffic performance data by vehicle categories and propulsion types **according to** the underlying **scenarios of Environment Agency Austria** (refer to chapter 2)
- detailed **traffic model data and analyses derived from** the application of the National Traffic Model **VMÖ** *[67]* (refer to chapter 3)
- a set of **adjustable input parameters and variables** with their values derived from literature research, stakeholder engagement (refer to chapter 4) and expert assumptions where necessary (for details see subsection 5.2)

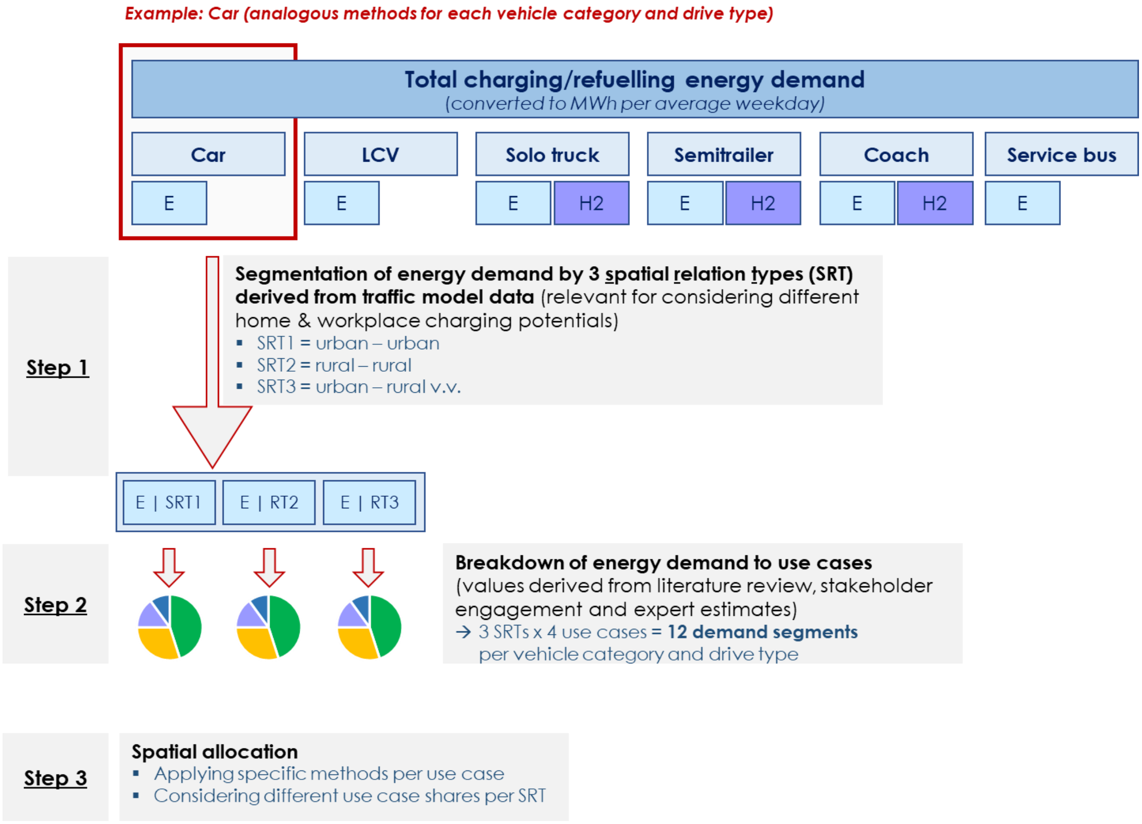
The model output can be summarized as follows:

Model output and presentation of results

- **Number of required charging points** respectively H2 refuelling points **per municipality** and **per motorway section** (based on official ASFINAG section list) as well as **corresponding energy amounts,** differentiated by charging capacity types and summed up over charging use cases
- **Aggregation to federal states and/or motorways** depending on charging use case (optional aggregations possible, e.g. to political districts)
- Preparation and presentation of results in the form of **tables, graphs** and **maps**

The flowchart in Figure 5-1 illustrates the general methodical modelling approach exemplarily for the vehicle type car. Analogous approaches are applied for the other vehicle categories and propulsion types.

Figure 5-1: General methodical approach | Exemple vehicle type car



Segmentation of energy demand by 3 spatial relation types (SRT) derived from traffic model data (relevant for considering different home & workplace charging potentials)
- SRT1 = urban – urban
- SRT2 = rural – rural
- SRT3 = urban – rural v.v.

Breakdown of energy demand to use cases
(values derived from literature review, stakeholder engagement and expert estimates)
→ 3 SRTs x 4 use cases = **12 demand segments** per vehicle category and drive type

Spatial allocation
- Applying specific methods per use case
- Considering different use case shares per SRT

In order to be able to model the current energy demand and the corresponding number of charging points in a profound way, the relevant charging / refuelling use cases have been defined based on literature review, stakeholder engagement and expert assessment. The following table Table 5-1 provides a systematic overview of the considered use cases per vehicle category. For each use case, specific charging point model types with underlaid charging capacities were used as calculation basis.

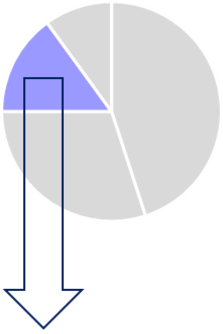
The following Figure 5-2 and Figure 5-3 describe the use case specific methodical approach used for the spatial allocation of energy demand and required charging / refuelling points for the exemplary use cases occasional/destination charging and range extension charging. Analogous approaches are applied for the other use cases.

Table 5-1: Overview of considered charging use cases

Vehicle categories and propulsion types		**Use Cases**		**Charging point types**
Light vehicles | E	**Car**	Private	**Home**	3.6 kW
				11 kW
				22 kW
		Private	**Workplace**	11 kW
				22 kW
	LCV	Private	**Origin** (business premises)	11 kW
				22 kW
	Car & LCV	Publicly accessible	**Occasional/destination** e.g. shopping, leisure, hotels as well as on-street parking in urban areas	11 kW
				22 kW
				50 kW
		Publicly accessible	**Range extension**	150 kW
				350 kW
HDV (HGV & Coach) | E		Private	**Origin** (business premises)	150 kW
				350 kW
		Private	**Destination** (business premises)	150 kW
				350 kW
		Publicly accessible	**Range extension** (overnight and fast charging)	150 kW
				350 kW
				1000 kW
Service Bus | E		Private	**Origin / En route** (subsumed in one use case)	150 kW
				600 kW
HDV (HGV & Coach) | H2		Private	**Origin**	*H2-station*
		Publicly accessible	**Range extension**	*H2-station*

Figure 5-2: Use case specific spatial allocation method | Example use case destination charging

Spatial allocation method | Use case occasional/destination charging

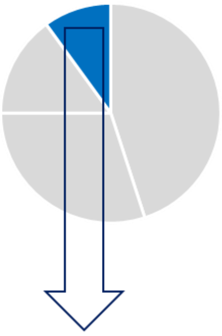


Regionalisation of use case specific energy amount using traffic model

- **Spatial distribution** of energy demand based on zone-specific attractivity potential for relevant trip purposes (shopping, leisure etc.; Spatial resolution: 6500 VMÖ traffic zones)
- **Allocation factors** derived from traffic model data: Weighted purpose-specific attractivity potential based on purpose-specific traffic demand and structural / POI data
- **Calculation of results** at municipality level (plus further regional aggregations)

Figure 5-3: Spatial allocation method | Use case puclic range extension charging

Spatial allocation method | Use case range extension charging



Regionalisation of use case specific energy amount using traffic model

- **Spatial distribution** of energy demand based on demand segment specific traffic volumes per road network segment
  - Differentiated by spatial relation type (SRT 1-3)
    → specific weighting regarding charging probabilities
  - Differentiated by trip length category
    (< 50 km, 50-100 km, 100-300 km, > 300 km)
    → specific weighting regarding charging probabilities
  - Spatial resolution: Detailed VMÖ road network model
- **Allocation factors** derived from traffic model analyses (demand segment specific traffic assignment to road network)
- **Calculation of results**:
  - Per motorway section for A+S network (plus further aggregation to motorways)
  - Per municipality for remaining road network (plus further regional aggregations)

5.2 Model input parameters and variables

In the following section, the main input parameters and variables used by the GREENROAD projection model (for general methodical approach refer to chapter 5.1) are described. Apart from the essential data sets presented in chapter 2 (overall energy demand) and chapter 3 (traffic model data derived from VMÖ) a set of adjustable input parameters and variables is used with their values derived from literature research, stakeholder engagement (refer to chapter 4) and expert assumptions where necessary. The relevant parameters are:

- **Vehicle related parameters** (see chapter 4.5 and Table 5-2)
  - Ø Battery capacity and range per vehicle category
  - Ø Initial charging status per spatial type and vehicle category
- **Charging point type and use case related parameters** (see Table 5-3)
  - Ø Daily turnover rate per use case and charging point type
  - Ø Capacity recharged per charging
- **Use case specific energy distribution parameters** (see Table 5-4)
  - Range extension charging probability
  - Percentage breakdown of energy demand to use cases

Table 5-2 to Table 5-4 give an overview of the relevant model input parameters. The specific input values used for the modelling projection in GREENROAD can be found in the excerpt of the config file included in the appendix of this report.

Table 5-2: Vehicle related model input parameters

Parameter	Differentiation
Energy capacity [kWh]	Vehicle types: *Car | E, LCV | E, Solo truck |E, Semitrailer | E, Coach | E, Service Bus | E, Solo truck | H2, Semitrailer |H2, Coach | H2* Forecast horizons: *2025, 2030, 2035, 2040*
Energy consumption [kWh/100km]	
Vehicle range [km]	
Initial energy status | urban [%]	
Initial energy status | rural [%]	

Table 5-3: Charging point and use case related model input parameters

Parameter	Differentiation
Share of charging point types per use case [%]	Vehicle types + Use cases and charging point types *(see Table 5-1)* Forecast horizons: *2025, 2030, 2035, 2040*
Daily turnover rate [chargings per workday]	
Capacity recharged per charging [%]	

The percentage of total energy demand that is allocated to specific use cases is set according to the differentiation presented in Table 5-4. Here, a two-step approach is applied:

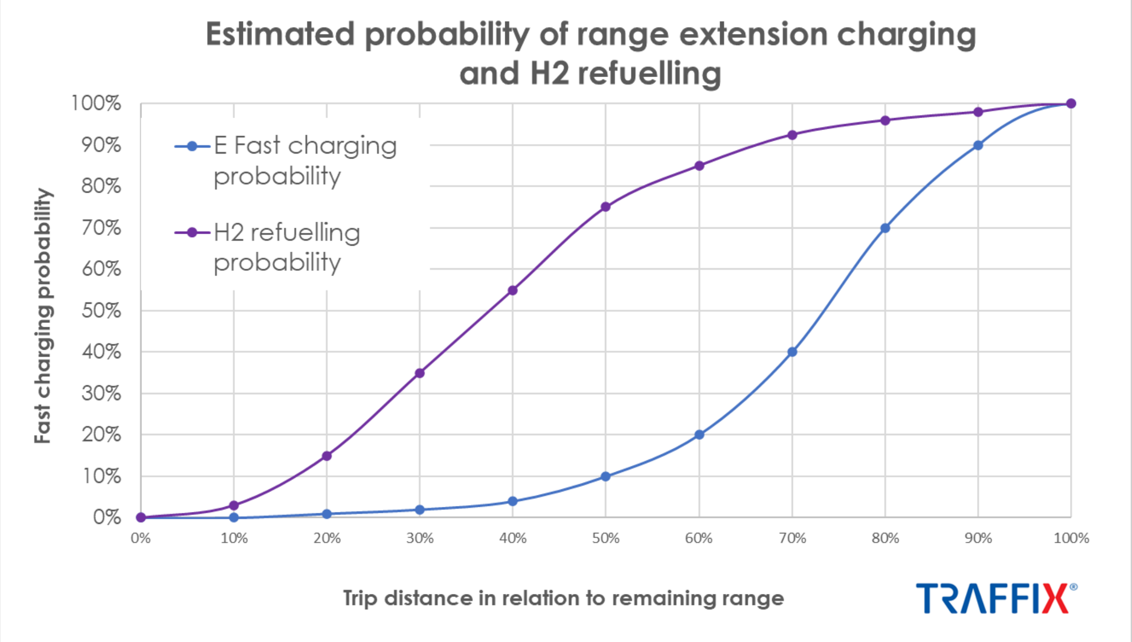
(1) The share of energy demand covered by publicly accessible range extension charging is derived from traffic model calculations considering trip length and spatial relation type (with different average initial charging status), in combination leading to differentiated probabilities for fast charging need. In the calculation model an estimated probability function depending on trip distance and remaining vehicle range as shown in Figure 5-4 is used. It is assumed that H2 refuelling will show a quite similar behavioural pattern like conventional gasoline or diesel refuelling. In contrast, EV charging at publicly accessible fast charging stations will only be used when no other options (private charging or occasional/destination charging) are available.

(2) For the remaining use cases, percentage shares are set individually by expert assessment, based on literature review and stakeholder engagement and taking into account the presumed technological and structural changes over time. In order to ensure a realistic use case distribution, in addition to the described bottom-up approach, complementary top-down plausibility checks per use case are integrated in the calculation model. For example, the resulting total number of private home charging points is compared to the overall number of households and the e-car fleet according to the underlaid market ramp-up.

Table 5-4: Use case specific energy distribution parameters

<table>
<tr><th colspan="5">Percentage breakdown of charging/refuelling energy to use cases [%]</th></tr>
<tr><th>Differentiation</th><th>Car</th><th>LCV</th><th>HDV</th><th>Service bus</th></tr>
<tr><td rowspan="4">Spatial relation types:
<i>SRT 1 | urban-urban</i>
<i>SRT 2 | rural-rural</i>
<i>SRT 3 | rural-urban v.v.</i>
Forecast horizons:
<i>2025, 2030, 2035, 2040</i></td><td>Home</td><td rowspan="2">Origin</td><td rowspan="2">Origin</td><td rowspan="4">Origin /
En route</td></tr>
<tr><td>Workplace</td></tr>
<tr><td>Occasional/
destination</td><td>Occasional/
destination</td><td>Destination</td></tr>
<tr><td colspan="3"><i>Range extension (derived from transport model)</i></td></tr>
</table>

Figure 5-4: Estimated probability of range extension charging depending on trip distance and remaining range



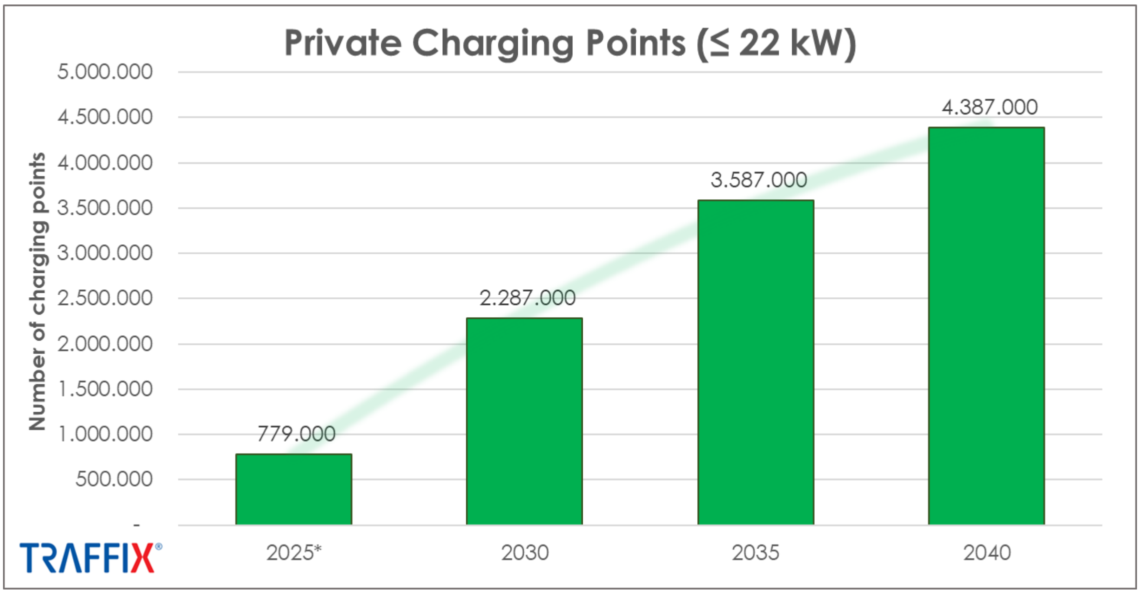
5.3 Results: Spatial allocation of projected demand for zero emission infrastructure

5.3.1 Cars and light commercial vehicles

Private charging

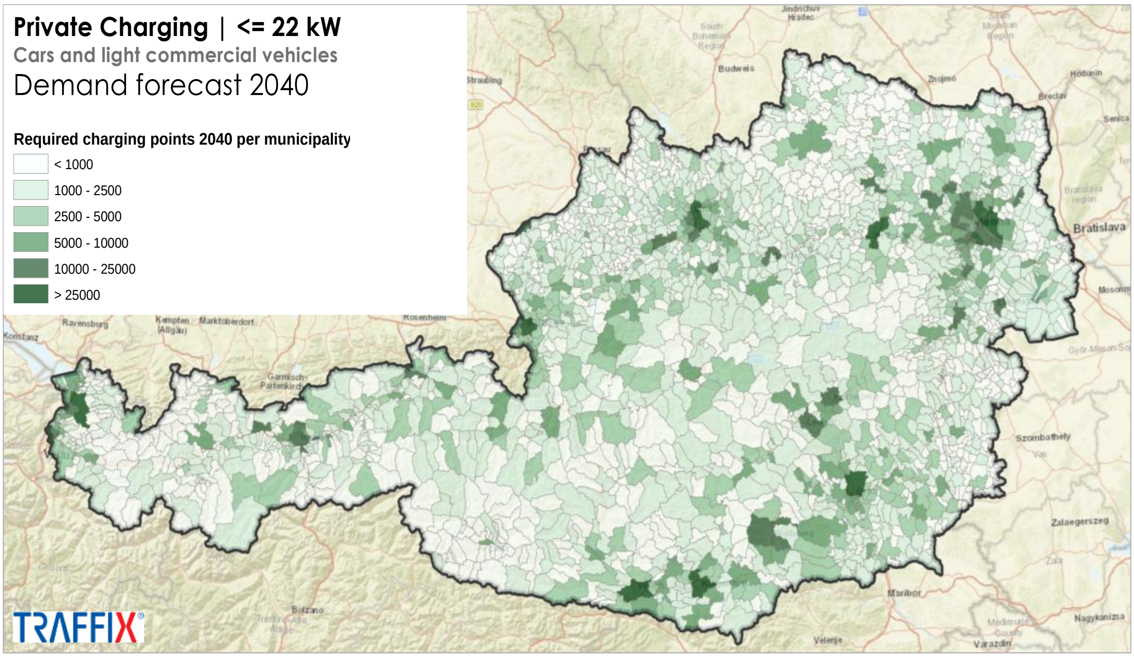
Based on the modelled charging demand, Figure 5-5 shows the required number of private charging points in 5-years steps until 2040 in Austria's private homes, at workplaces and at business premises for light commercial vehicles. In total, nearly **2.3 million private charging points** are required **by 2030** and nearly **4.4 million by 2040**. As the results of the GREENROAD projection model provide detailed information on municipality level, the map in Figure 5-6 indicates the spatial distribution of the required private charging points by municipalities. Foreseeable that metropolitan areas with high population density can easily be identified as areas with high demand, although these urban areas have a relatively smaller share of private charging because of their lower availability of private parking spaces compared to rural areas.

Figure 5-5: Forecast demand for private charging points in Austria 2025-2040



* Note: Because the e-mobility market ramp-up is currently lagging behind compared to the underlying Transition Mobility Scenario *[26] [27] [28]* (refer to chapter 2), the demand projection for 2025 is likely to be overestimated. Thus, the growth rate between 2025 and 2040 will need to be accordingly steeper.

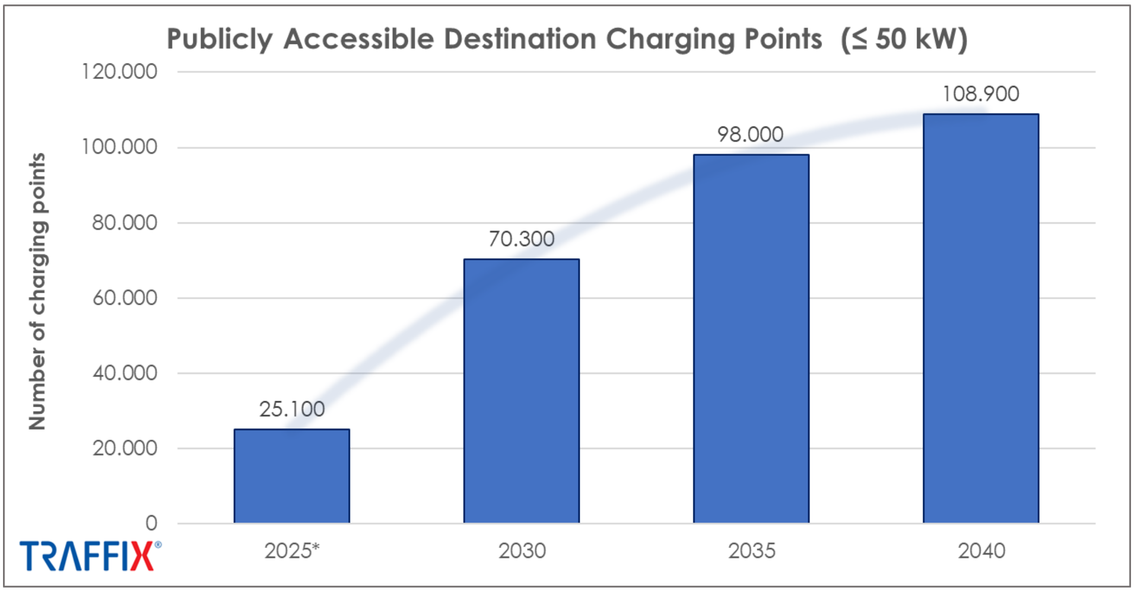
Figure 5-6: Spatial allocation of demand for private charging points 2040



Publicly accessible or occasional charging

Based on the modelled charging demand, Figure 5-7 shows the required number of publicly accessible occasional/destination charging points in 5-years steps until 2040 for private cars and light commercial vehicles in Austria. **By 2030,** approx. **70 300** and **by 2040** approx. **108 900 publicly accessible destination charging points** are required. Based on the current state in 2022, the **expansion factors** required to reach these projected numbers are **4.9 until** 2030 and **7.6 until** 2040. As the results of the GREENROAD projection model provide detailed information on regional level, the map in Figure 5-8 indicates the spatial distribution of the required publicly accessible destination charging points by municipalities. For this use case, in particular the attractivity of a municipality for shopping, leisure or touristic trips is a key factor for the charging demand potential. Hence, metropolitan areas are dominant with the highest numbers of required charging points. Especially in urban regions the requirement of publicly accessible on-street charging points, that is covered by the use case occasional/destination charging according to the GREENROAD use case definition, will play an important role. In addition, demand accumulations in well-known touristic destinations can be clearly identified on the map. Figure 5-9 shows the spatial demand distribution aggregated to the level of federal states.

Figure 5-7: Projected demand for publicly accessible destination charging points in Austria 2025-2040



* Note: Because the e-mobility market ramp-up is currently lagging behind compared to the underlying Transition Mobility Scenario *[26] [27] [28]* (refer to chapter 2), the demand projection for 2025 is likely to be overestimated. Thus, the growth rate between 2025 and 2040 will need to be accordingly steeper.

Figure 5-8: Spatial allocation of demand for publicly accessible destination charging points 2040

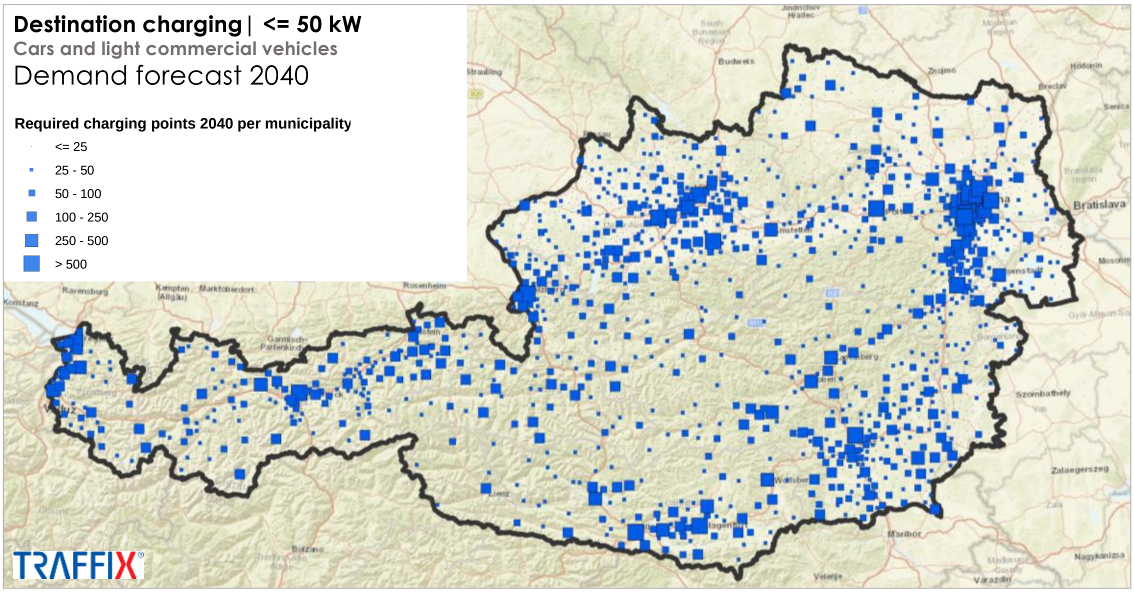
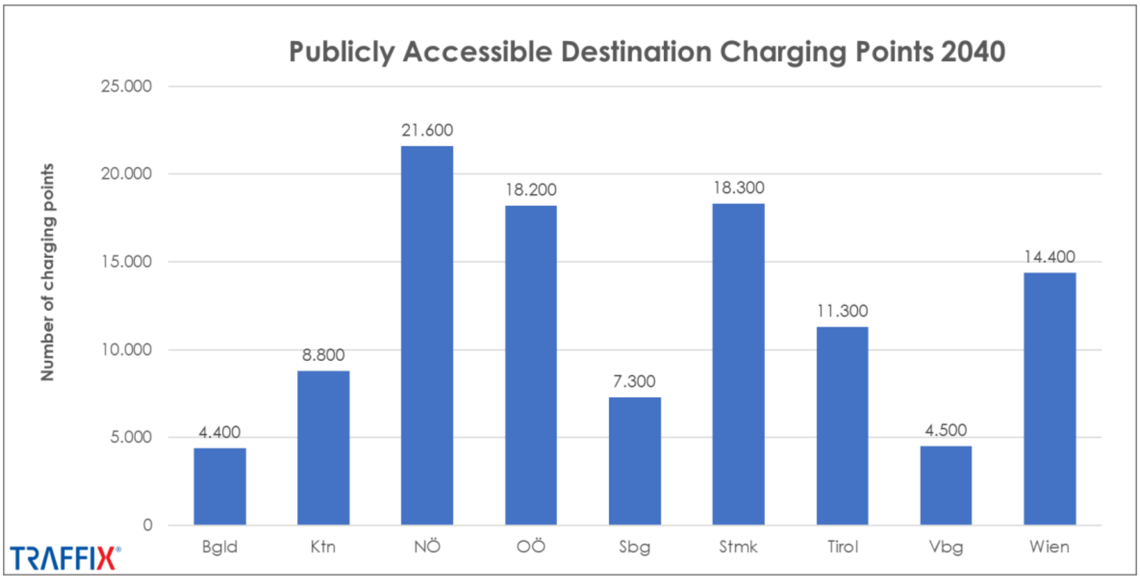


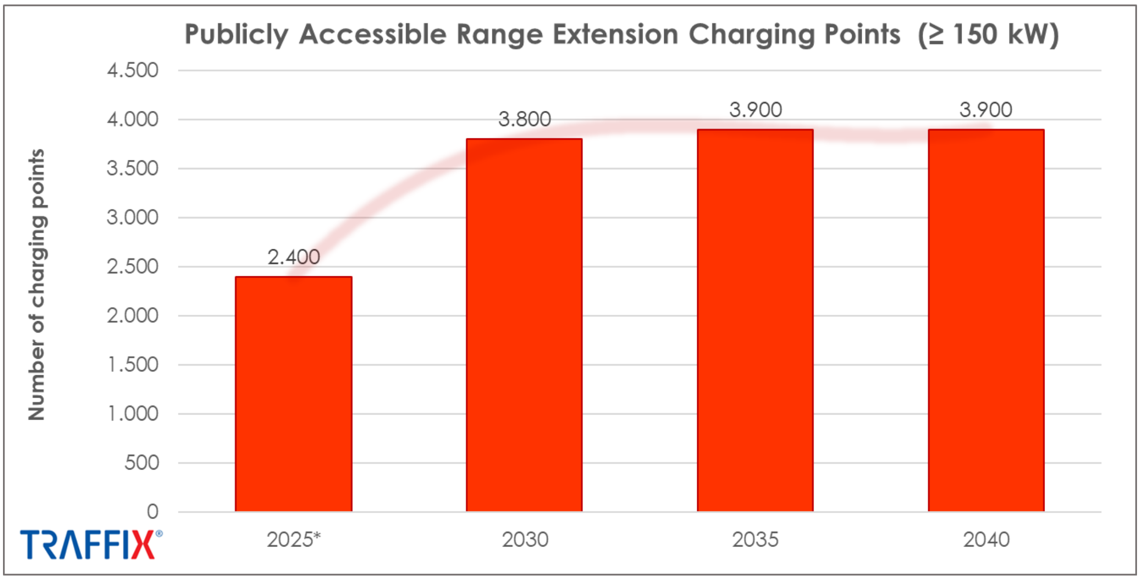
Figure 5-9: Demand for publicly accessible destination charging points 2040 by federal state



Publicly accessible range extension charging

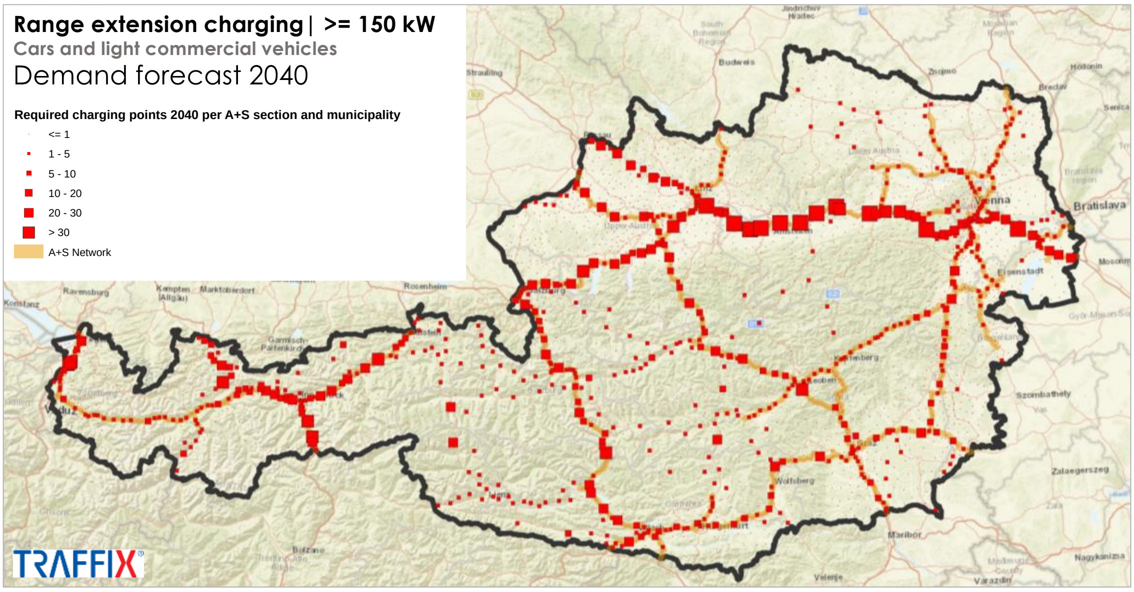
Based on the modelled charging demand, Figure 5-10 shows the required number of publicly accessible high-power range extension charging points in 5-years steps until 2040 for private cars and light commercial vehicles in Austria. **By 2030** approx. **3 800** and **by 2040** approx. **3 900 publicly accessible high-power range extension charging points** are required. Based on the current state in 2022, the **expansion factors** required to reach the projected numbers are **5.4 until** 2030 and **5.6** until 2040. In contrast to private and publicly accessible destination charging, the demand peak for high-power range extension charging is already expected in the early 2030s. After that, with a growing number of available private charging stations and higher average vehicle ranges, a saturation effect occurs and the demand remains relatively stable until (and after) 2040. The results of the GREENROAD projection model provide detailed information on regional level as well as per section of the motorway network. Map in Figure 5-11 shows the spatial distribution of the required publicly accessible range extension charging points by municipalities and by motorway sections. Apart from the motorway network, which of course plays a dominant role here, well-known routes in the federal roads network that have a high relevance for traffic with longer trip distances, can be identified. Examples are the routes along B100 (Drautal), B108 (Felbertauern), B179 (Fernpass), B180 (Reschenpass) or B320 (Ennstal).

Figure 5-10: Projected demand for publicly accessible range extension charging points in Austria 2025-2040



* Note: Because the e-mobility market ramp-up is currently lagging behind compared to the underlying Transition Mobility Scenario *[26] [27] [28]* (refer to chapter 2), the demand projection for 2025 is likely to be overestimated. Thus, the growth rate between 2025 and 2040 will need to be accordingly steeper.

Figure 5-11: Spatial allocation of demand for publicly accessible range extension charging points 2040

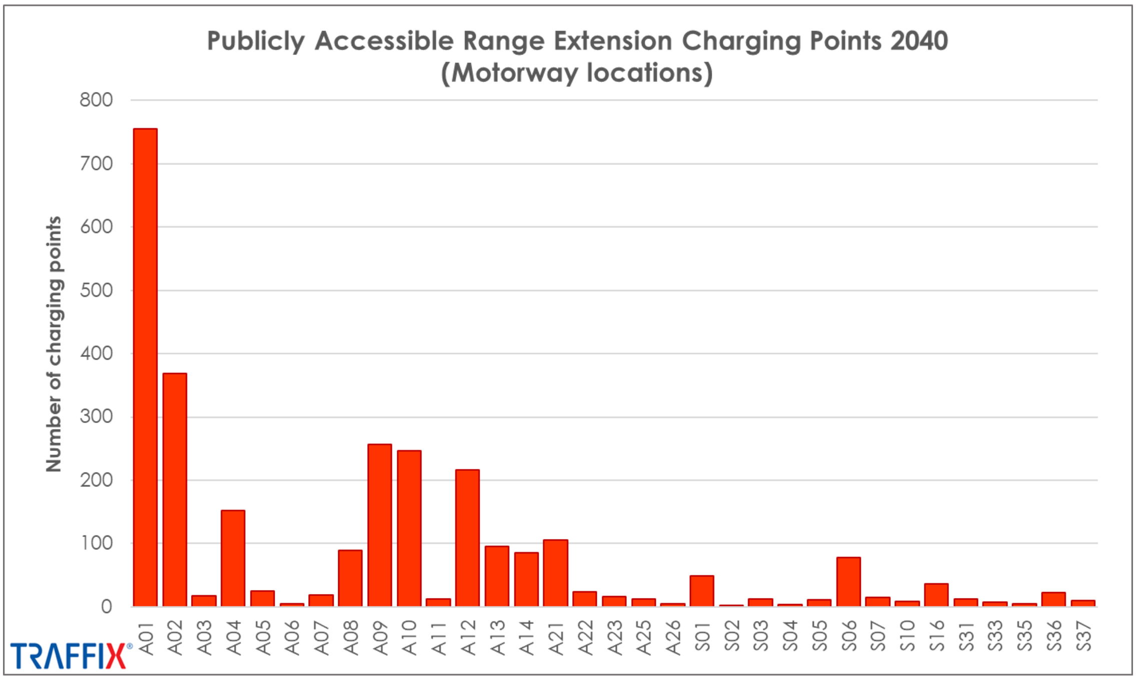


Explanation: The calculation model operates on the level of motorway sections according to the official ASFINAG section list (representing each section between two motorway junctions) and on municipality level for the remaining network. For the purpose of an illustrative graphical visualization of the spatial demand distribution, the map shows a dot for each motorway section respectively for each municipality. This does not mean that each dot represents a single charging station location. In reality, a charging station location will cover the aggregated demand of neighbouring dots.

Figure 5-12 and Figure 5-13 show the number of range extension charging points 2040 aggregated by motorway sections for locations on or near motorways respectively aggregated by federal states for the remaining network. Due to the combination of route length and traffic volumes, the A1 motorway has by far the highest demand potential, followed by A2, A9, A10 and A12. For some busy motorways in urban areas like e.g. the A23 in Vienna the charging point demand is quite small because the routes itself are short and/or local traffic with shorter trip distances play a dominant role there.

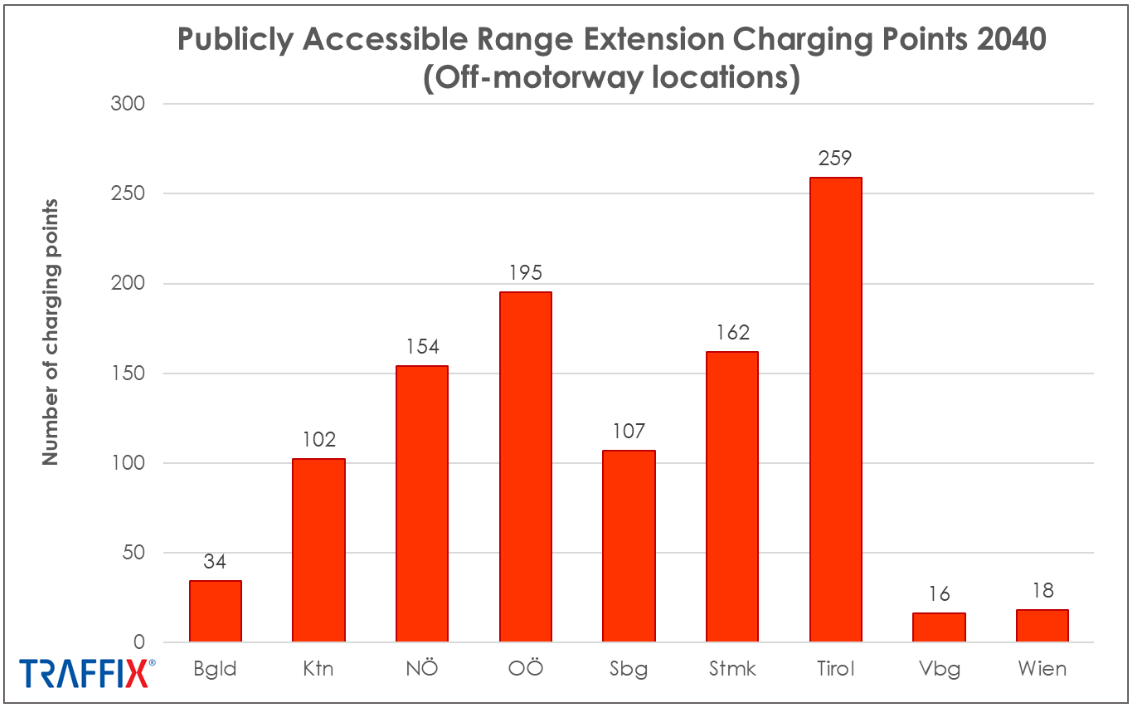
Concerning off-motorway locations the highest demand for range extension charging is generated in Tirol due to some of the above-mentioned federal roads with transit route characteristics (e.g. Fernpass and Reschenpass).

Figure 5-12: Demand for publicly accessible range extension charging points 2040 by motorway



Note: Including locations on or in close proximity to motorways

Figure 5-13: Demand for publicly accessible range extension charging points 2040 by federal state (excluding locations on or near motorways)



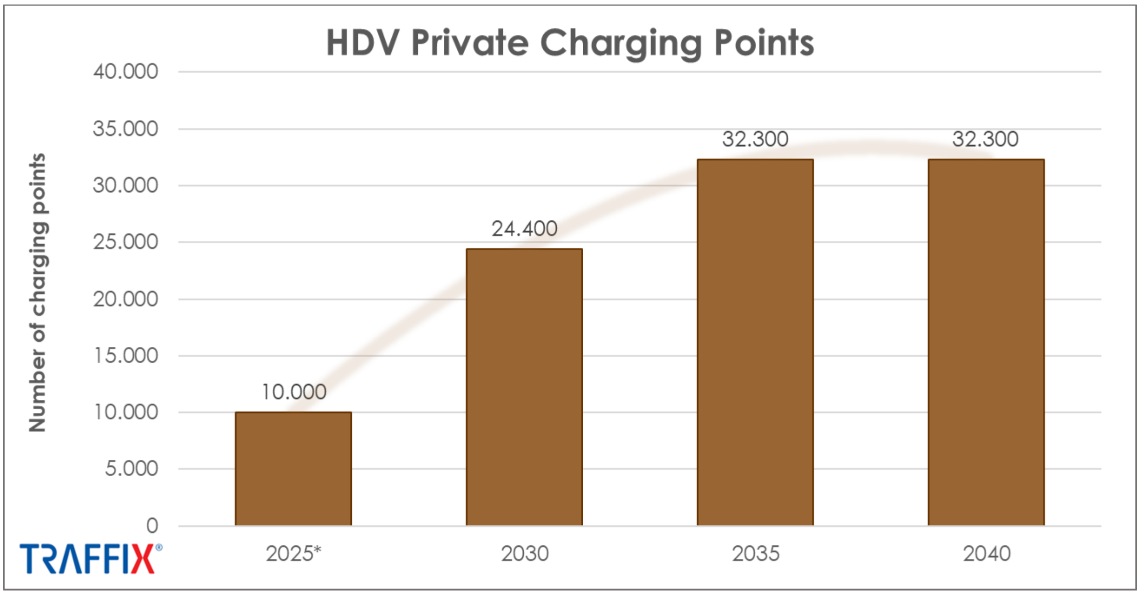
Note: Excluding locations on or in close proximity to motorways

5.3.2 Heavy duty vehicles

Private charging at business premises

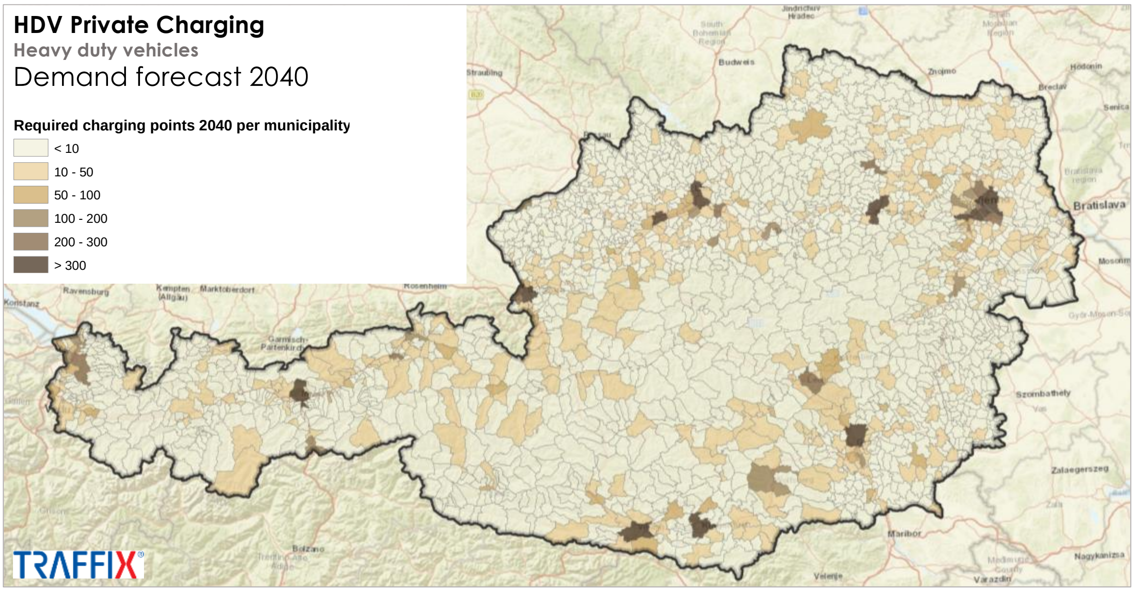
Based on the modelled charging demand, Figure 5-14 shows the required number of private HDV charging points in 5-years steps until 2040 for heavy goods vehicles and coaches in Austria. **By 2030,** around **24 400** and **by 2040** around **32 300 private charging points** are required at business premises. After 2035 the projection model shows a saturation effect. This is due to the fact that private charging points can be used more efficiently (with higher daily turnover rates) as soon as whole truck and coach fleets become fully electrified. As the results of the GREENROAD projection model provide detailed information on municipality level, the map in Figure 5-16 indicates the spatial distribution of the required private HGV charging points by municipalities. Similar to the required distribution of private charging points for cars and LCVs, urban and suburban areas can be clearly identified as they in many cases have a high number of HDV-relevant businesses. In addition, single municipalities where intermodal terminals are located (e.g. Wels, Villach, Wörgl, Brennersee) can be identified as they are considered as high-potential locations in the projection model.

Figure 5-14: Projected demand for private HDV charging points in Austria 2025-2040



* Note: Because the e-mobility market ramp-up is currently lagging behind compared to the underlying Transition Mobility Scenario *[26] [27] [28]* (refer to chapter 2), the demand projection for 2025 is likely to be overestimated. Thus, the growth rate between 2025 and 2040 will need to be accordingly steeper.

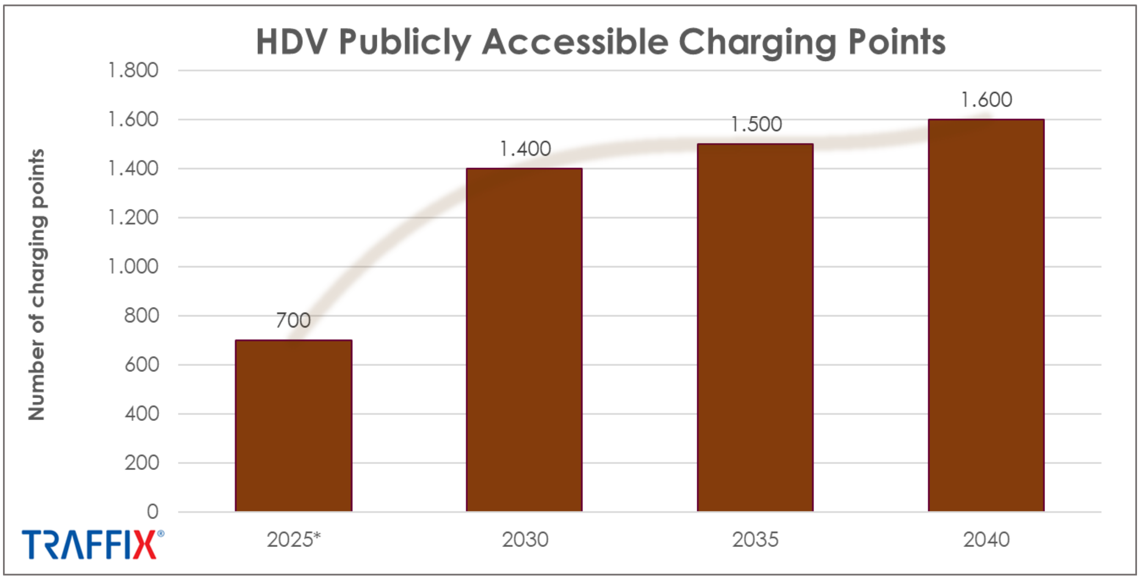
Figure 5-15: Spatial allocation of demand for private HDV charging points 2040



Publicly accessible HDV charging

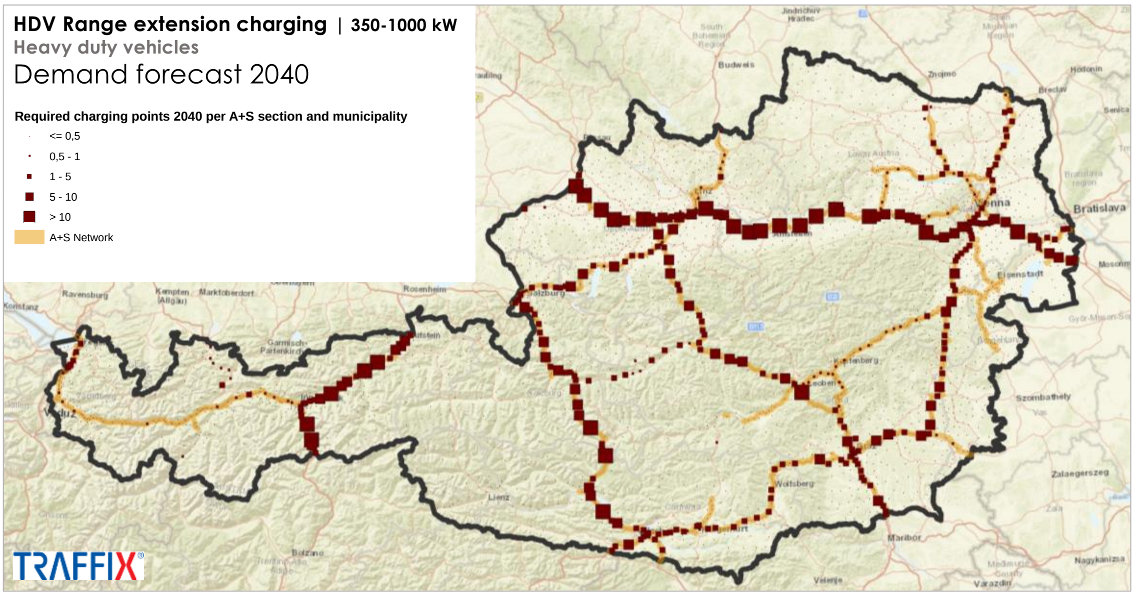
Based on the modelled charging demand, Figure 5-16 shows the required number of publicly accessible HDV charging points in 5-years steps until 2040 for heavy goods vehicles and coaches in Austria. **By 2030** approx. **1 400** and **by 2040** approx. **1 600 publicly accessible HDV charging points** are required. Thereof, around **70 %** should be **overnight-chargers** (mainly located at already existing motorway rest and parking areas) with approx. 150 kW and **30 %** so-called **megawatt chargers**. Like for cars and light commercial vehicles, the demand **peak for high-power range extension charging** is already expected **during the 2030s**. After that, there occurs a saturation effect and the demand for publicly accessible HDV charging remains relatively stable until (and after) 2040. The results of the GREENROAD projection model provide detailed information on regional level as well as per section of the motorway network. The map in Figure 5-17 shows the spatial distribution of the required HDV charging points by municipalities and by motorway sections. Apart from the motorway network, which of course plays a clearly dominant role here, only single routes in the federal road network that have a certain relevance for long-distance HGV traffic like especially the B320 (Ennstal) can be identified.

Figure 5-16: Projected demand for publicly accessible HDV charging points in Austria 2025-2040



* Note: Because the e-mobility market ramp-up is currently lagging behind compared to the underlying Transition Mobility Scenario *[26] [27] [28]* (refer to chapter 2), the demand projection for 2025 is likely to be overestimated. Thus, the growth rate between 2025 and 2040 will need to be accordingly steeper.

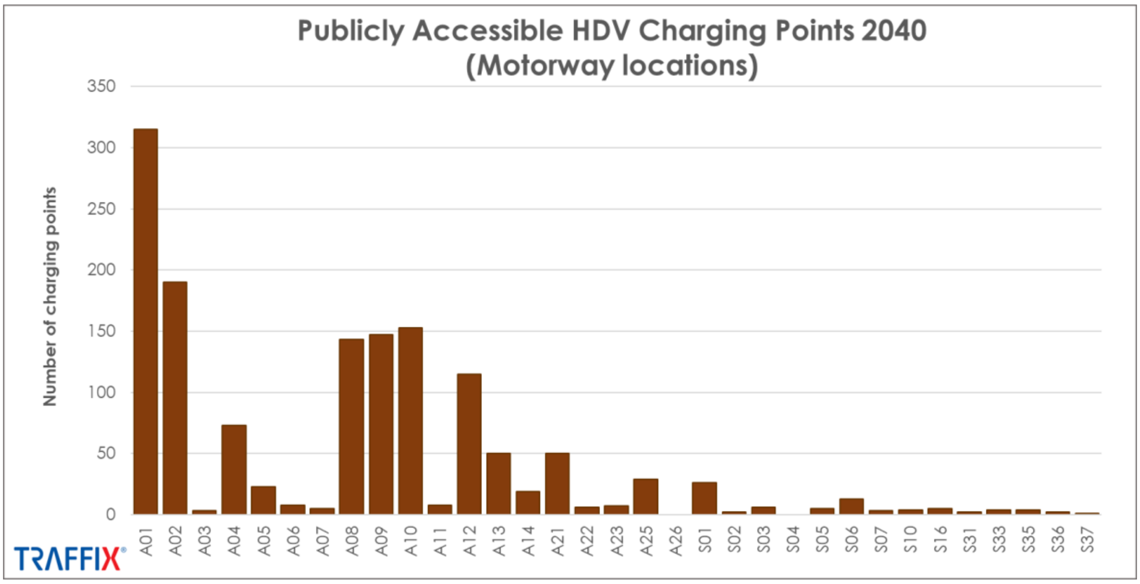
Figure 5-17: Spatial allocation of demand for publicly accessible HDV charging points 2040



Explanation: The developed calculation model operates on the level of motorway sections according to the official ASFINAG section list (representing each section between two motorway junctions) and on municipality level for the remaining network. For the purpose of an illustrative graphical visualization of the spatial demand distribution, the map shows a dot for each motorway section respectively for each municipality. This does not mean that each dot represents a single charging station location. In reality, a charging station location will cover the aggregated demand of neighbouring dots.

Figure 5-18 and Figure 5-19 show the number of HDV charging points 2040 aggregated by motorway sections for locations on or near motorways respectively aggregated by federal states for the remaining network. Due to the combination of route length and heavy traffic volumes, the A1 motorway has by far the highest demand potential, followed by A2, A10, A9, A8 and A12, which more or less represent the most important heavy vehicle transit routes in Austria. For some busy motorways in urban areas like e.g. the A23 in Vienna the charging point demand is quite small because the routes itself are short and/or long-distance heavy traffic doesn't play a dominant role there. Concerning off-motorway locations the highest demand for range extension charging is generated in Oberösterreich, Steiermark and Niederösterreich.

Figure 5-18: Demand for publicly accessible HDV range extension charging points 2040 by motorway

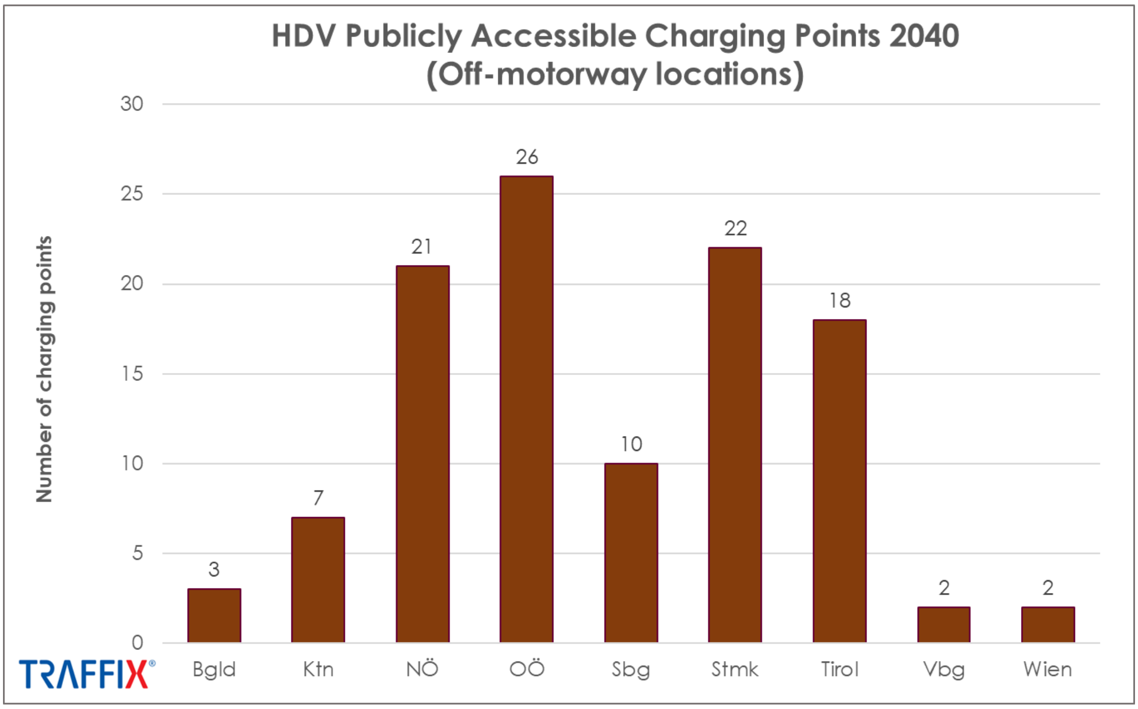


Note: Including locations on or in close proximity to motorways

Excursus: Electric road systems

The R&D project Energy Roads *[1]* examined the feasibility of an electric road system (ERS) using an overhead line for dynamic charging of heavy vehicles. According to this study, for potential users and vehicle manufacturers the technology will only be of interest with a certain prospect of a growing network throughout Europe. Thus, a possible future realization of ERS depends on the prerequisite of a clear political commitment to a widespread roll out of a standardized infrastructure to gain momentum in the development. Currently it is still unclear which role electric road systems will actually play in the long term. In the event that selected motorway sections along the TEN-T network will be equipped with ERS, the projected number of required HDV charging points could be reduced to a certain degree.

Figure 5-19: Demand for publicly accessible HDV range extension charging points 2040 by federal state (excluding locations on or near motorways)

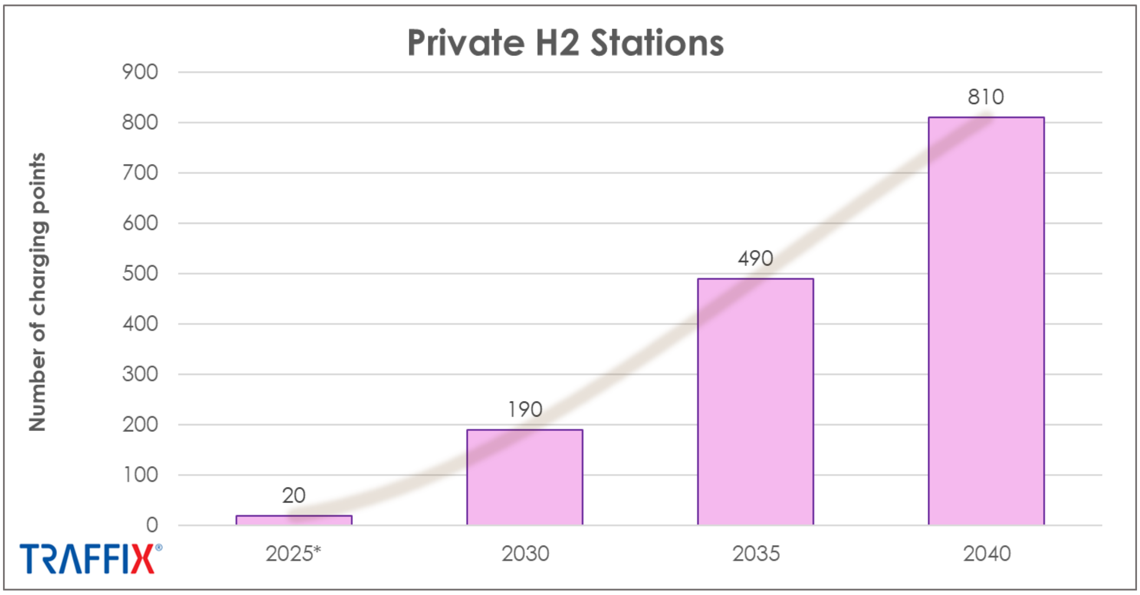


Note: Excluding locations on or in close proximity to motorways

Private and publicly accessible H2 stations

Figure 5-20 and Figure 5-22 show the required numbers of private and publicly accessible H2 fuelling stations in 5-years steps until 2040 in Austria. Currently experts assume that hydrogen will gain a certain importance for long distance transport and especially for heavy load transport. However, larger vehicle fleets will only emerge after 2030. Pioneer fleet operators (e.g. commercial enterprises and larger transport operators) predominantly are expected to build their own private infrastructure. Therefore, at the moment the pressure on the publicly accessible H2 refuelling infrastructure is not as crucial as for the electric charging infrastructure. The principal objective is to offer a basic refuelling infrastructure in line with the European development goals especially along the TEN-axes. The model results project a requirement of nearly **200 private H2 refuelling points** at business premises **by 2030** and approx. **800 by 2040**. Regarding publicly accessible H2 refuelling, the results show a requirement of around **70 publicly accessible H2 refuelling points by 2030** and **130 by 2040**.

Figure 5-20: Projected demand for private H2 refuelling points in Austria 2025-2040



* Note: Because the hydrogen market ramp-up is currently lagging behind compared to the underlying Transition Mobility Scenario *[26] [27] [28]* (refer to chapter 2), the demand projection for 2025 is likely to be overestimated. Thus, the growth rate between 2025 and 2040 will need to be accordingly steeper.

Figure 5-21: Spatial allocation of demand for private H2 refuelling points 2040

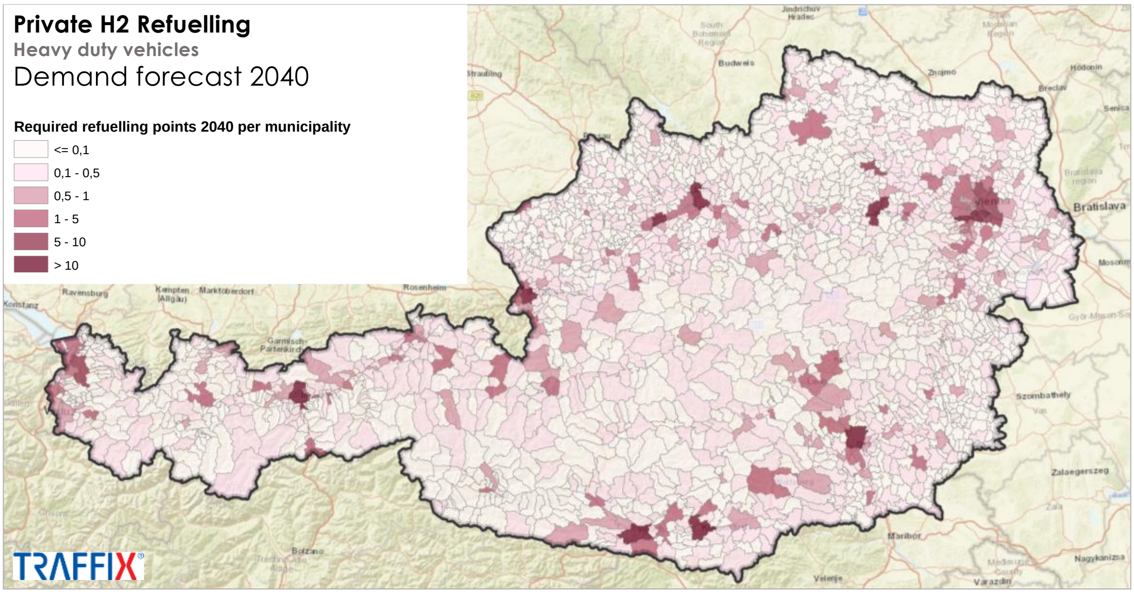
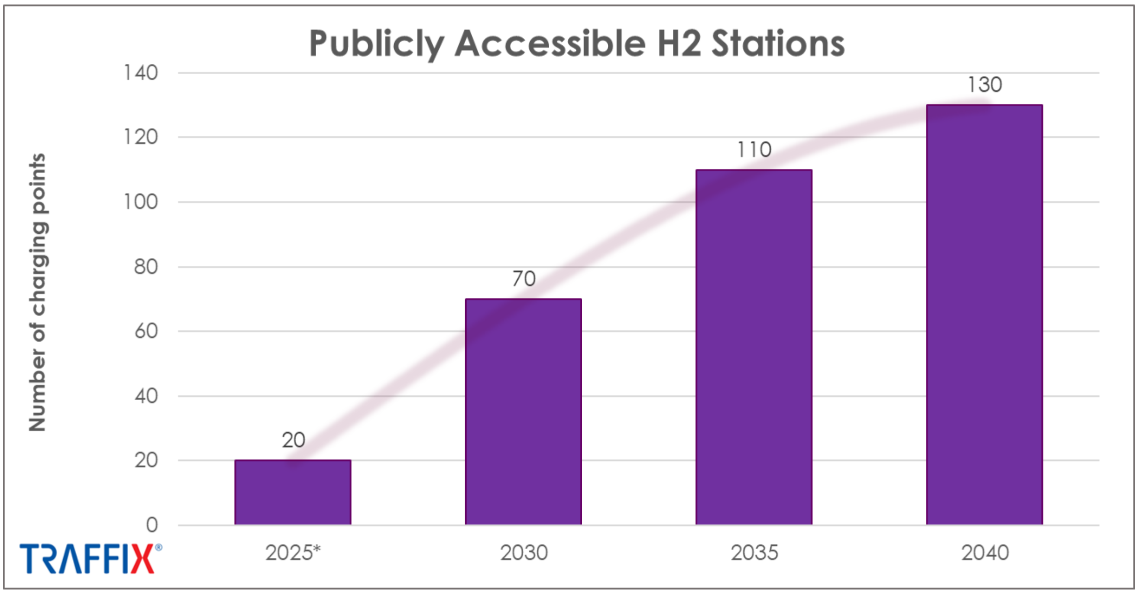
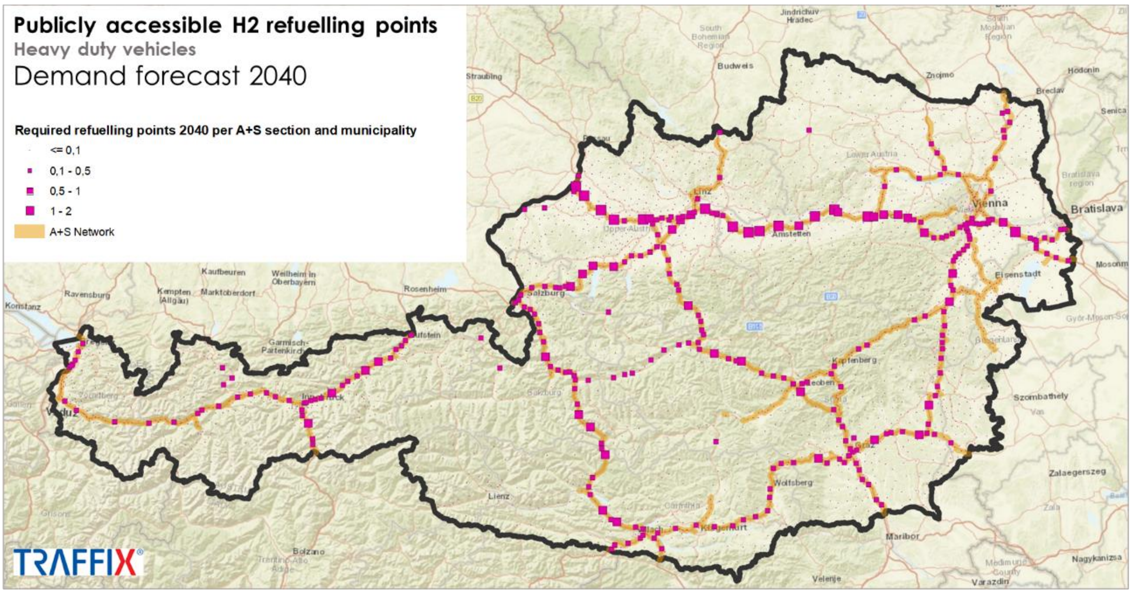


Figure 5-22: Projected demand for publicly accessible H2 refuelling points in Austria 2025-2040



* Note: Because the hydrogen market ramp-up is currently lagging behind compared to the underlying Transition Mobility Scenario *[26] [27] [28]* (refer to chapter 2), the demand projection for 2025 is likely to be overestimated. Thus, the growth rate between 2025 and 2040 will need to be accordingly steeper.

Figure 5-23: Spatial allocation of demand for publicly accessible H2 refuelling points 2040

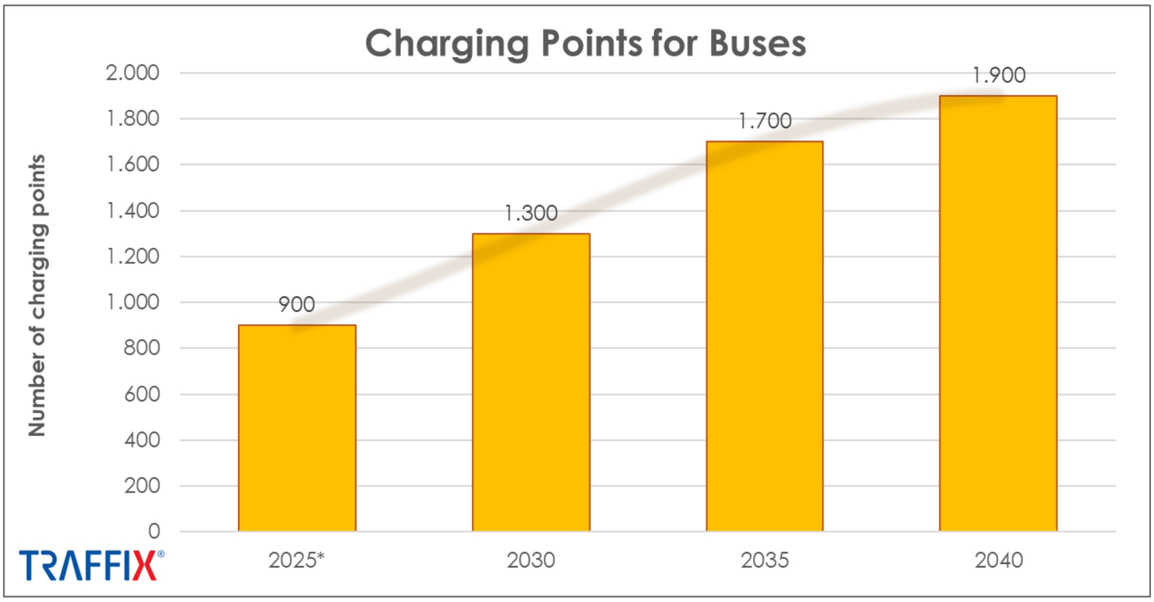


Explanation: The developed calculation model operates on the level of motorway sections according to the official ASFINAG section list (representing each section between two motorway junctions) and on municipality level for the remaining network. For the purpose of an illustrative graphical visualization of the spatial demand distribution, the map shows a dot for each motorway section respectively for each municipality. This does not mean that each dot represents a single charging station location. In reality, a charging station location will cover the aggregated demand of neighbouring dots.

5.3.3 Buses of public transport services

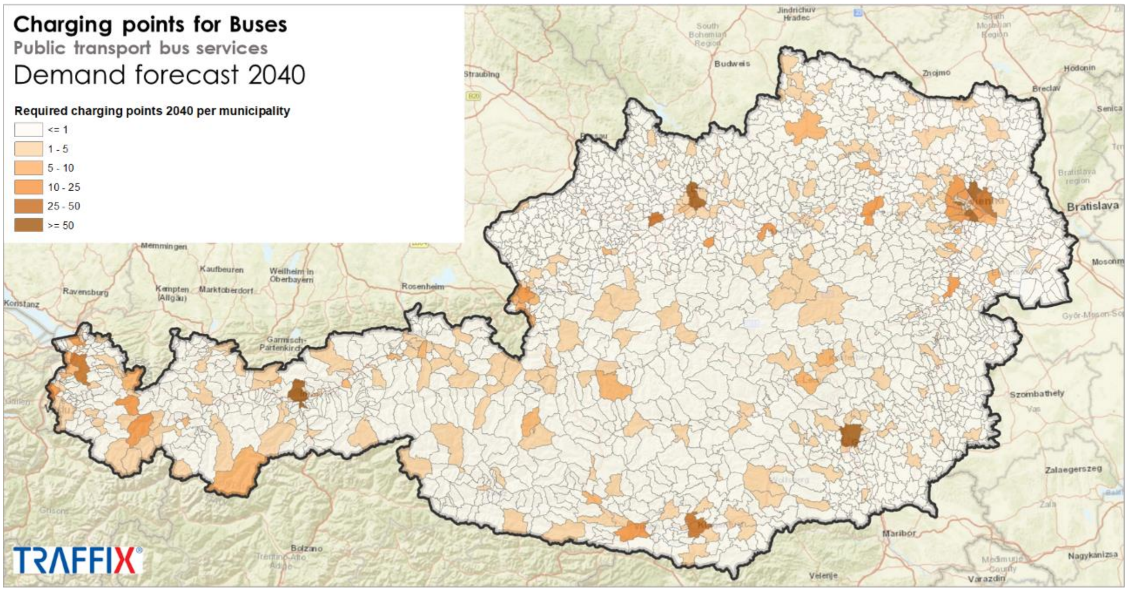
Based on the modelled charging demand, Figure 5-24 shows the required number of charging points for public transport buses in 5-years steps until 2040 in Austria. **By 2030,** around **1 300** and **by 2040** around **1 900 charging points** are required. It is assumed that these charging points will mainly be located at bus depots (mainly for overnight charging) on the one hand and at relevant stations of the public transport networks (mainly for recharging during the day) on the other hand. The map in Figure 5-25 shows the spatial distribution of the required charging points for public transport buses. Unsurprisingly, the regions with the highest demand potential are urban areas with correspondingly attractive public transport bus services.

Figure 5-24: Projected demand for public transport bus charging points in Austria 2025-2040



* Note: Because the e-mobility market ramp-up is currently lagging behind compared to the underlying Transition Mobility Scenario *[26] [27] [28]* (refer to chapter 2), the demand projection for 2025 is likely to be overestimated. Thus, the growth rate between 2025 and 2040 will need to be accordingly steeper.

Figure 5-25: Spatial allocation of bus charging points 2040



6 TECHNICAL AND LEGAL CONDITIONS REGARDING ZERO EMISSION INFRASTRUCTURE

6.1 Procedure

In three focus groups, experts on mobility and energy discussed on the future development of zero emission infrastructure. The findings of the workshops are summarized in the following sub-chapters. Technical and legal conditions for zero emission infrastructure differ depending on whether infrastructure for electric charging or hydrogen refuelling is considered. Therefore hydrogen and electric infrastructure are described separately in each chapter.

Battery electric propulsions were in general considered as the currently most developed technology, with the exception of trucks > 18 t. Overhead catenary systems (e-Highways) are not considered as relevant by the experts. First, as they do not have any advantages in terms of efficiency compared to battery electric vehicles, second, as overhead catenary systems require a European solution and third, as the systems are not yet fully developed.

Hydrogen was not considered as an option for vehicles below 3.5 t. Also for heavy duty vehicles it is not yet clear what share of hydrogen powered vehicles will be in use in the next years. Especially, as fuel cells for heavy duty vehicles are not yet competitive. Also experts agreed that hydrogen will furthermost be required for industrial applications like the production of energy-intensive products, peak load management and as (renewable) energy storage. Currently however, the biggest challenge related to hydrogen is that it is not available in the required quantities and quality – neither produced in Austria, nor for import.

6.2 Technical conditions

6.2.1 General

The technical conditions required for zero emission infrastructure vary significantly between the different technologies. However, as – especially for heavy duty vehicles – it is not yet clear which technology will be used in the future, it is important to remain open to all technologies. The technologies used are to a large degree specified by the manufacturers. As vehicles are mainly produced in foreign regions, Austria has to provide the infrastructure for the emerging technologies in order not to have a regional handicap. This is especially important for the freight transport sector, because if freight companies use a technology for which Austria does not provide the necessary infrastructure, this will result in commercial disadvantages for Austria.

Relevant for zero emission infrastructure in general is that new infrastructure requires space, which is not available everywhere. The specific requirements for charging and hydrogen refuelling infrastructure will be described in the following chapters.

6.2.2 Electricity

6.2.2.1 Space requirements for charging infrastructure

From a technical perspective, accessibility, a minimum size (depending on the number and type of vehicles that will use the charging infrastructure) and a sufficiently strong connection to the electric grid are necessary. In cities, charging stations should also be located close to a transport hub. However, technical items have to be linked to legal items.

In Germany a digital platform called “FlächenTOOL” *[52]* provides information about properties that are potentially available for the construction of charging infrastructure. Owners of properties (municipalities, companies, private individuals etc.) can offer their properties via the “FlächenTOOL”. The platform is provided by the National Charging Infrastructure Control Centre on behalf of the Federal Ministry of Transport and Digital Infrastructure and is online since 2020. However, the “FlächenTOOL” does not always provide all required technical information, especially with regard to the relevant informations on the electricity grid.

A similar platform, ideally also integrating the information about the available connection to the electric grid, could facilitate the construction of charging infrastructure also in Austria. Currently in Austria only a platform with information about the location of the charging stations *[56]* exists.

6.2.2.2 Connection to electric power grid

Currently, it can take up to two years until a (larger) connection to the electric power grid is constructed, which can be seen as a hindrance to the construction of charging infrastructure. The distribution system operator (DSO) has to upgrade the technical infrastructure in the local grid, such as transformers or fuses, which requires time for planning, procurement and installation. The implementation of load management systems can avoid or decrease the required work and hence the time delay.

6.2.2.3 Publicly accessible charging

E-car charging (AC / slow charging)

Publicly accessible e-car charging is mainly equipped with AC charging stations (slow charging). Payment system runs according to the time. From a practically point of view customers look for charging by power consumed (by kWh) and not by time. On the other hand some degree of time-based charging will have to be maintained to prevent drivers from using the charging station as parking lot. Therefore, if billing by kWh is introduced, other technical solutions are required to prevent drivers from using the charging station as parking lot.

E-car charging (DC / fast charging)

Currently, in Austria there are no technical specifications available concerning the calibration of DC charging stations. Therefore, no calibrated DC charging stations are available on the market and billing according to consumed power (by kWh) is not cleared sufficiently. By an increasing demand for fast charging stations, it will be necessary to provide calibration regulations as well as technical specifications for the calibration of DC charging stations. Presently (November 2022) a draft for such a regulation is under review (see chapter 6.3.2).

e-bike charging

For e-bikes one of the main technical challenges is the **lack of a uniform plug connector.** The batteries of e-bikes can usually be charged via a regular 230 V socket by using the appropriate charging cable. Thus, tor charging on the ride, users always are required to carry the charging cable with them. Even then publicly accessible charging is difficult, as charging stations with 230 V sockets are rarely available in public space. The reason behind it is, that 230 V sockets could be used by all kinds of electric devices, which is not the intention of charging stations. At the same time, with the increasing usage of cargo bikes by delivery services, charging in the public space (en route) becomes more important. Also, more and more e-bikes have a non-removable battery and require accessible charging infrastructure. Thus, a technical standard for plug connectors for e-bike charging needs to be introduced. Further, publicly accessible charging stations for e-bikes need to be developed that take into account the difficulty of 230 V sockets in public space.

6.2.2.4 Charging at home / at work

E-car charging

For electric cars there are specifications concerning charging in residential buildings. In each new / renovated residential building with more than 10 parking spaces, electrical installation tubes have to be prepared so that it is possible to install charging stations. It is also required to provide an electrical connection infrastructure for these charging stations (i.e. § 6 (3b) Wiener Garagengesetz). The requirements for charging power provisions differ between the Austrian federal states. There are no technical specifications concerning the configuration of the charging station (e.g. "personalized" charging station, common charging station, billing options, load management etc.). The revision of the EPBD directive *[50]* in the context of the Fit for 55 package *[41]* stipulates some regulations.

e-bike charging

Contrary to car parking and e-car charging, there are no technical requirements concerning the quality of bike parking or charging facilities in residential buildings (e.g. type of bicycle stands, weather protection, charging facilities etc.). In Vienna, the only specifications that were introduced recently concern the number of bike parking places per m² living space (1 bike parking space per 30 m² living space in new/renovated buildings, §119 (5) Bauordnung für Wien).

It is recommended to introduce technical requirements for the quality of bike parking facilities – including charging facilities – in residential buildings in the building codes of the federal states (Bauordnungen).

Billing of charging at home / at work

In residential buildings, usually the property management is responsible for the accounting. Especially when charging stations are installed in existing buildings, it is difficult to establish a propriate payment system, as both, information and experience is lacking. This applies for both, electric cars and e-bikes. However, in the case of e-bikes the energy demand is quite low compared to electric cars, so the administration costs for the billing might be higher than the charging costs from the e-bike users. Also, for charging at work there still is a need for further clarification and the introduction of tools to simplify the processes.

6.2.3 Hydrogen

6.2.3.1 Hydrogen filling stations

Hydrogen filling stations have large space requirements. The minimum size ranges from 80 m² if only cars and vans are refuelled, to 250 m² for a refuelling station suitable also for trucks and buses (H2 Mobility GmbH 2021). Further, hydrogen filling stations need to be spatially segregated from regular fuel stations (see chapter 6.3). Along the Austrian highway network it is quite open, how the oil companies will deal with the topic of hydrogen filling stations and whether they are planning to sell hydrogen at all (see also chapter 6.3).

A lot of research is being conducted in the hydrogen sector in Europe. *[53]* However for the construction of hydrogen filling stations long construction periods must be expected as technical standards for the construction of hydrogen refuelling stations are lacking.

For hydrogen filling stations frequent use to withdraw hydrogen is an operational requirement in order to minimize evaporation. Experts recommend for this reason to develop the infrastructure together with use-cases. Between hydrogen refuelling stations, a distance of approx. 200 km in the TEN-T core network is recommended. Therefor it will be necessary to coordinate the investments with neighbouring countries. It should be started to install a basic supply of hydrogen filling stations in the TEN-T core network (5-6 filling stations in Austria).

In general, it is estimated that the development of hydrogen infrastructure is around 6 years behind the development of infrastructure for e-mobility. For making hydrogen as an energy carrier a feasible option is necessary to develop technical standards for the construction of hydrogen filling stations. These standards should be equal for all 9 Austrian provinces. Also, a coordination body for hydrogen corridors in Europe should be established.

6.2.3.2 Availability of hydrogen

Hydrogen suitable for usage in fuel cells needs to be of a very high quality (high purity hydrogen). However, this is not available in large quantities and the available amounts are also required for other applications. Thus, investments in production facilities for high-quality green hydrogen are necessary. In this context, specifications are given by the current Delegated regulation on Union methodology for RFNBOs. *[49]*

6.3 Legal conditions

6.3.1 General

6.3.1.1 Building codes

Austria has nine different building codes. Therefore, federal procedures for the construction of zero emission infrastructure would be desirable, especially when it comes to up-scaling zero emission infrastructure.

6.3.1.2 Rest and Service stations

Along highways, zero emission infrastructure can only be installed at or close to already existing service stations. Due to the longer time needed for refuelling the vehicles there will be needed additional space at the service sites.

6.3.1.3 Road charge / Toll

Currently zero emission trucks can benefit from a toll reduction of 75 % (in Germany even 100 %). As there are not yet many zero emission trucks on the roads, this can be neglected. However, it will become relevant once zero emission trucks become increasingly available on the market. Firstly, the ASFINAG as relevant body for the maintenance of the highways loses toll revenues; secondly, freight companies require planning security concerning the costs of freight transport, as they will weigh the higher acquisition costs of zero emission vehicles against the lower toll costs. Thus it is important to consider how the toll system and the financing system of the national road network has to be organized in accordance to a higher number of zero emission trucks.

6.3.1.4 Alternative Fuel Infrastructure Regulation (AFIR)

According to the AFIR regulation *[42]*, it is envisaged that binding distance-related targets for charging points and hydrogen filling stations for heavy goods vehicles will be introduced in the TEN-T network, which must be implemented by the member states. However, the concrete implementation still needs to be clarified, including whether ASFINAG, as the infrastructure operator, is legally obligated to make these investments. Further, ASFINAG will not be the operator for zero emission infrastructure, so in case ASFINAG is responsible for the installation of the infrastructure, models for the operation of the infrastructure need to be developed.

6.3.2 Electricity

6.3.2.1 Calibration regulations

If a measuring device for electrical energy is used at a charging station, it is mandatory according to the Austrian calibration law (§8 Maß- und Eichgesetz) to calibrate this device. For this, it is necessary that the BEV (Bundesamt für Eich- und Vermessungswesen) issues the required calibration regulations. Presently (November 2022) these regulations are still under review. This is especially relevant for DC charging stations (fast charging), where operators would like to do the billing by consumed power (by kWh). Without a calibration regulation, this is not possible or if, then a legal grey area, as non-calibrated measuring devices are used (see also chapter 6.2.2). For AC charging stations, this issue is not of such a high relevance, as – first – mainly time-based billing is used and – second – there are already calibrated measuring devices available. In order to accelerate the installation of fast charging stations, the adoption of the calibration regulation is urgently needed.

6.3.2.2 Installation of charging stations

If the installation of charging stations will be made possible by a simple notification under the Austrian Electricity Industry and Organization Act (ElWOG), it would be great. As far as the infrastructure for fast charging (range extension) is concerned, the experts tend to believe that this needs to be driven by the public sector. The main reason for this is that there is still some uncertainty as to which technology (hydrogen / electricity) will dominate in freight transport and thus no self-regulation of the market can be expected. For ASFINAG it is further not clear, whether they are required by law to invest in this kind of infrastructure (see chapter 6.3.1.4). Furthermore, it was suggested to make the installation of charging infrastructure mandatory via the Austrian fuel ordinance (KVO – Kraftstoffverordnung) or to implement regulations for fuel distributors ("Kraftstoffinverkehrbringer"). In fact, the KVO already provides incentives for fuel distributors, i.e. the possibility to take electricity amounts into account for the achievement of defined targets.

6.3.2.3 Charging at home / at work

European requirements need to be incorporated into national building regulations (e.g. OIB guidelines). Also, national regulations concerning charging at home and charging at work are lacking, as it falls within the competence of the states. For charging at home, the regulations in residential buildings need to be revised in order to facilitate the installation of charging stations for both, proprietaries and tenants.

State law in Niederösterreich, for example, requires the provision of electric infrastructure with a defined charging power for each parking space in specific residential buildings. In Vienna on the other hand, state law merely requires the construction of empty piping, but no provisions for charging power are made. Since the subsequent reinforcement of the building grid connection is costly, it is suggested to add requirements for charging power to the Vienna Garage Act (Wiener Garagengesetz).

In Austria, the law for proprietaries (WEG – Wohnungseigentumsgesetz) has been recently modified such as to facilitate the installation of charging station ("right-to-plug"). However, similar modifications of the laws that concern buildings where people are renting the apartments (MRG – Mietrechtsgesetz, WGG – Wohnungsgenossenschaftsgesetz) are lacking. For charging at work experts estimate that incentives and subsidies are better than obligations. Further, experts note that figures on the number of private charging stations – both at home and at work – are missing.

6.3.2.4 Publicly and semi-publicly accessible charging

Concerning publicly accessible charging, experts suggest to reduce the number of regular parking spaces in order to create space for charging stations combined with loading areas. This is especially important for business mobility in cities – e.g. craftspeople, delivery services. For semi-publicly accessible charging (supermarkets, hotels etc.), regulations concerning for the number of charging stations, similar to the regulations concerning handicapped parking spaces, should be implemented. The challenge, however, is that supermarkets, especially in urban areas, are usually existing buildings, which makes it difficult to retrofit charging infrastructure. Also for semi-publicly accessible charging stations, experts note that figures on the number of such charging stations are missing.

6.3.3 Hydrogen

6.3.3.1 Construction of hydrogen filling stations

Concerning the construction of hydrogen filling stations and hydrogen infrastructure in general, there are still many legal issues to clarify. Two issues raised by the experts are – firstly - the legal safety distance to other buildings, residential areas etc. when building a hydrogen filling station and – secondly– the fire load for hydrogen vehicles in tunnels.

7 COSTS AND PUBLIC SUPPORT OPTIONS

7.1 Quantifying the cost of zero emission road traffic infrastructure development

The **total costs** of constructing the zero emission infrastructure required by 2040 are calculated by combining information on the number of required charging/refuelling points from chapter 5 with information on unit costs per charging/refuelling point derived from expert judgements. The latter were derived from a purpose-built questionnaire, which was sent to participants of the stakeholder workshops described in section 0, in particular those of focus group 2, “Charge point operators and technology”. For the purpose of this study, **unit costs** cover the costs of construction and connecting a new charging/refuelling point, including hardware and assembly (installation, wiring) as well as construction work for the foundation and, if relevant, excavation works. Connection fees to the electricity grid are also included, as they are the proportionate costs of basic infrastructure and load management for shared charging in multi-family dwellings and at the workplace.

Not included in the unit costs are any potential network expansion costs that may be required to increase the power supplied by the electricity grid for charging at higher power. Since these costs relate to grid infrastructure, they are beyond the scope of this study, which is concerned with the charging/refuelling infrastructure. Also, administrative costs are excluded, such as costs incurred for approval and planning of charging points as well as for location search and signposting.

7.1.1 Unit costs per charging point and refuelling station

To gain information on the unit costs of building and connecting the required zero emission infrastructure, a questionnaire was set up and sent to representatives of charging/refuelling technology operators in Austria. The questionnaire asked for the unit costs as defined above, differentiated by:

- **Vehicle type:** Light vehicles (cars & LCV), HDV (HGV & coach) and service bus
- **Propulsion type:** Battery-electric or H2 fuel-cell electric
- **Use cases (private):** Home, workplace, place of origin and place of destination
- **Use cases (public):** Occasional/destination, range extension
- **Power:** 3.6 kW – 1000 kW for charging points, no differentiation for H2 refuelling stations

To account for cost differences within the use case “home”, it was further disaggregated into single- vs. multi-family homes in the questionnaire. The questionnaire was sent out to representatives of the following Austrian companies:

- Wien Energie GmbH
- EVN AG
- Energie AG Oberösterreich
- Scharinger Consulting
- SMATRICS GmbH & Co KG
- PAYUCA GmbH
- Compleo Charging Solutions AG
- OMV AG
- TIWAG
- Telco Sales Services GmbH

Of these ten contacts, seven sent back the filled-in questionnaire, two gave qualitative answers and one was unable to provide information. Figure 7-1 below summarises the questionnaire responses on the unit costs of the following **private use cases for battery-electric light vehicles (E-cars & E-LCV)**, differentiated by charging power in kW:

- Home charging, in both single- and multi-family homes (E-cars)
- Charging at the workplace (E-cars)
- Charging at the place of origin (E-LCV)

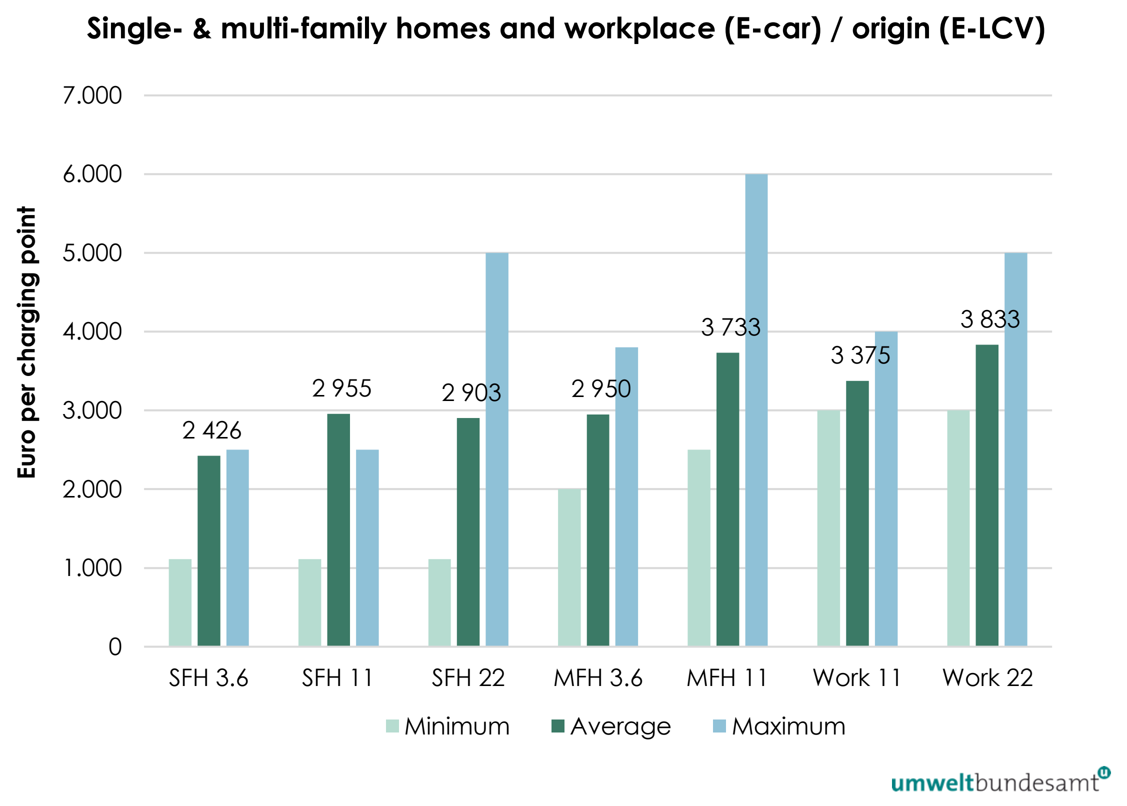
Since cars and LCV can use the same charging cables and the same infrastructure, the costs per charging point are identical for the last two use cases, charging at the workplace for private cars and charging at the point of origin for LCV.

The first three groups of bars in Figure 7-1 provide the minimum, mean and maximum questionnaire responses on the unit costs of charging points for electric cars in single-family homes (SFH) at 3.6, 11 and 22 kW (mostly individual wall boxes). On the whole, the unit costs provided a range between 1 110 and 5 000 Euro, with averages from 2 426 Euro at 3.6 kW to approximately 2900 Euro at 11 and 22 kW. For multi-family homes (MFH), the two middle bar groups, the average cost of a charging point is 2 950 Euro at 3.6 kW and 3 733 Euro at 11 kW. The questionnaire respondents included cost numbers for both shared and individual charging solutions. Charging points with 22 kW are not considered, as these would require an expansion of the power supplied from the electricity network in the case of shared access. As noted above, this study is only concerned with the costs of charging/refuelling infrastructure expansion, not grid infrastructure expansion.

Comparing the average unit costs for SFH and MFH at 3.6 and 11 kW, the costs for installing and connecting charging points in a MFH are slightly higher than in an SFH. This is due to the higher costs of basic infrastructure and load management for shared access in MFH, which were allocated proportionately to the unit costs per charging point by the questionnaire respondents.

The final two bar groups in Figure 7-1 show the unit costs of charging points for electric cars at the workplace and for LCV at their place of origin, which are identical given that both can use the same infrastructure. The average unit costs are 3 375 Euro at 11 kW and 3 833 Euro at 22 kW. The range of the questionnaire responses is narrower than for home charging, but average costs are comparable to MFH 11 kW albeit slightly lower. This could be because workplace charging benefits from existing connections to the electricity grid.

Figure 7-1: Costs per charging point | Private use cases for battery-electric cars & LCV



Description: SFH = single-family homes, MFH = multi-family homes, Work = workplace (cars) = place of origin (LCV); average unit costs indicated per use case and charging power; charging power given in kW

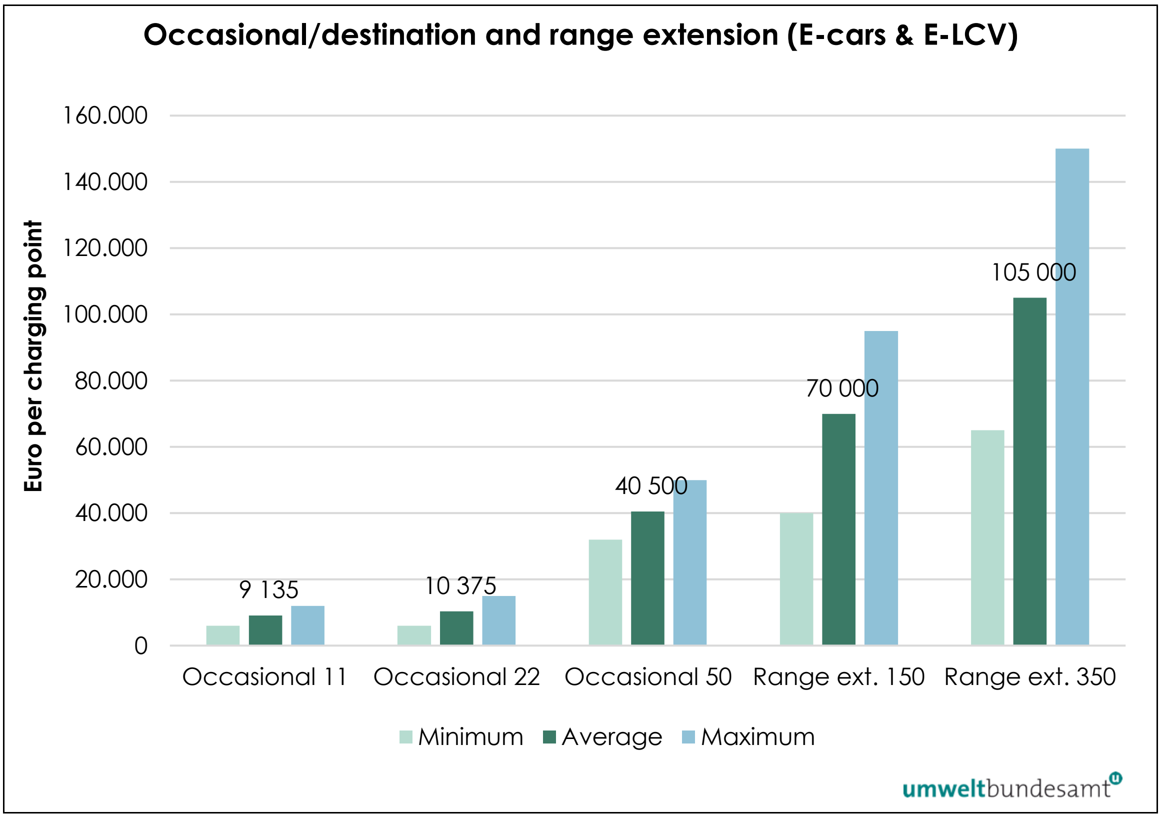
Source: Umweltbundesamt questionnaire, own calculations

Figure 7-2 depicts the questionnaire responses on the unit costs of the following **public use cases for battery-electric light vehicles (E-cars & E-LCV)**, again differentiated by charging power in kW:

- Occasional / destination charging
- Fast charging for range extension

Both, cars and LCV, can make use of the same infrastructure, why costs are identical for the two vehicle types. For occasional charging at the destination (first three bar groups in the figure), average unit costs vary between 9 135 Euro at 11 kW and 40 500 Euros at 50 kW. In contrast to the private use cases above, the publicly accessible charging points require construction work for excavation and foundation and are therefore more expensive. As they are higher-powered, also the hardware, assembly and network connection costs differ from the private use cases. The same holds for the fast charging points for range extension (last two bar groups), which cost on average 70 000 Euro at 150 kW and 105 000 Euro at 350 kW.

Figure 7-2: Costs per charging point | Public use cases for battery-electric cars & LCV



Description: Occasional = occasional/destination charging (E-cars & E-LCV); average unit costs indicated per use case and charging power; charging power in kW

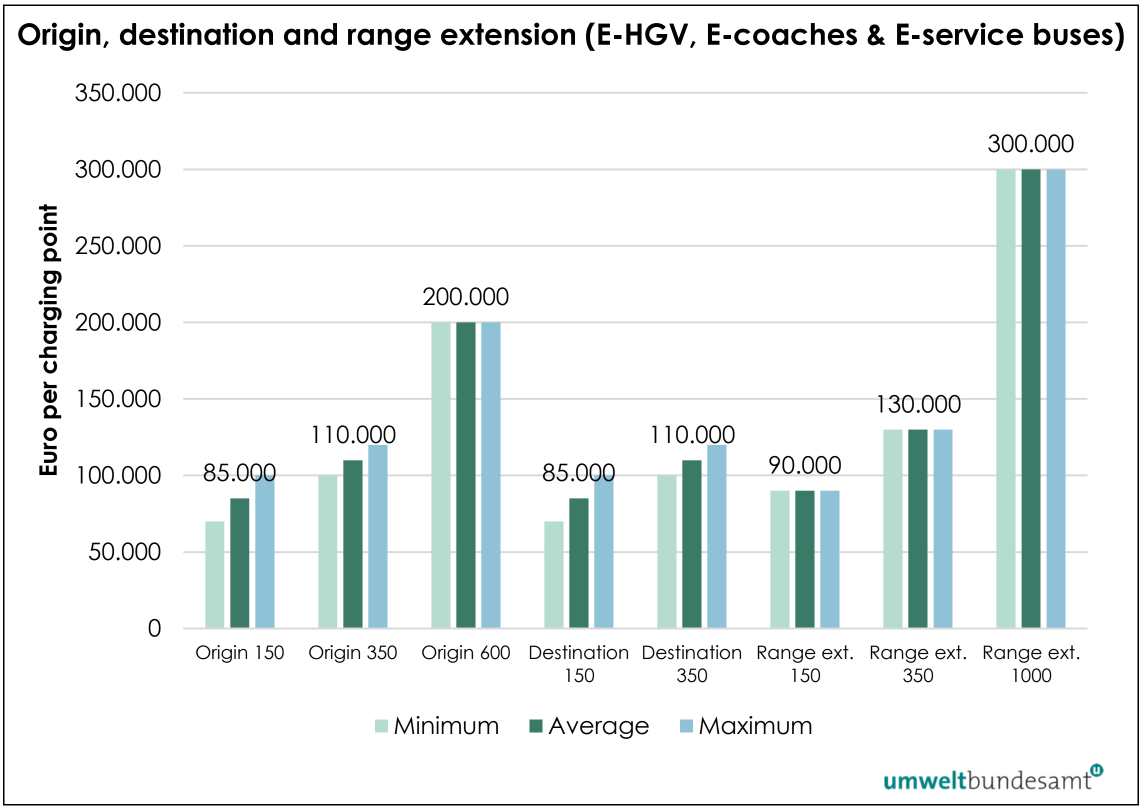
Source: Umweltbundesamt questionnaire, own calculations

Figure 7-3 illustrates the unit costs of charging points for the following **public and private use cases for battery-electric HDV and service buses (E-HGV, E-coaches & E-service buses)** by charging power in kW:

- Charging at the place of origin (private)
- Charging at the destination (private)
- Fast charging for range extension (public)

Battery-electric HDV and buses are able to share the same charging infrastructure. Therefore, costs per charging point are assumed to be identical for the first and third use cases, which apply to both vehicle types. For private charging at the place of origin, average unit costs for E-HGV, E-coaches and E-service buses amount to 85 000 Euro at 150 kW and 110 000 Euro at 350 kW. For 600 kW – a charging category that applies only to E-service buses – there was only a single questionnaire response indicating a cost of 200 000 Euro per charging point (hence minimum, mean and maximum are identical at 600 kW in Figure 7-3).

Figure 7-3: Costs per charging point, private & public use cases for battery-electric HDV



Description: Average unit costs indicated per use case and charging power; charging power in kW

Source: Umweltbundesamt questionnaire, own calculations

At the point of destination – a use case that only applies to E-HGV and E-coaches but not to E-service buses – unit costs are found to average at 110 000 Euro at 150 kW and 135 000 at 350 kW. The questionnaire respondents thus considered the costs at place of destination to be quite the same as those at place of origin, most likely because both use cases are private and should require similar infrastructure.

For publicly accessible fast charging for range extension, average unit costs are 90 000 at 150 kW, 130 000 at 350 kW and 300 000 at 1000 kW. Again, there was only one questionnaire response for this use case, so minimum, average and maximum unit costs are identical per power category. The cost of a publicly accessible fast-charging point for range extension is thus slightly higher than that of a private charging point at place of origin and destination for the corresponding power category. As for cars and LCV, this difference is likely due to greater infrastructure and construction requirements as well as higher hardware costs and grid connection fees in the public use case.

Finally, for H2-driven HDV (H2-HGV & H2-coaches), two questionnaire responses on the unit costs of H2 refuelling stations were obtained for the following **private and public use cases:**

- Charging at the place of origin (private)
- Fast charging for range extension (public)

In both cases, the unit costs are estimated at 3 million Euro per H2 station. These are assumed to apply to both H2-HGV and H2-coaches.

7.1.2 Total public infrastructure costs for charging and H2 refuelling points

Multiplying the unit costs presented in section 7.1.1 with the additional number of charging points respectively refuelling points required per period according to the results of chapter 5.3 yields the total costs of constructing and connecting the zero emission infrastructure by 2040. Table 7-1 summarises the resulting total costs for the public use cases per 5-year period, vehicle category and propulsion type, using the average questionnaire responses from the previous section.

As Table 7-1 below shows, the total **costs of expanding the public zero emission infrastructure** range between just over 400 million Euro and close to 1.2 billion Euro per 5-year period. Overall, the **total costs amount to 3.3 billion Euro until 2040, in average corresponding to around 181 million Euro per year** as from 2022.

The lion's share of the total public costs with 80 % on average is due to the expansion of publicly accessible charging infrastructure for battery-electric cars and LCV. This is in turn driven by the need for erecting charging points for occasional charging at publicly or semi-publicly accessible destinations such as at hotels, supermarkets or at the roadside in urban areas. As illustrated in Table 7-1, the costs of expanding occasional/destination charging for E-cars and E-LCV rise from an initial level of about 150 million Euro to continuously high levels of 600-800 million Euro throughout the 2030s. The costs of fast-charging points for range extension, on the other hand, start out at a similar level at 120 million Euro, only to then drop by more than half in the 2030s, to between 45-55 million Euro. By contrast, the use case occasional/destination charging plays no role for HGV and coaches, whether battery-electric or H2-powered. The only public use case that is relevant for these vehicle categories is range extension, either as fast-charging points or publicly accessible H2 refuelling stations. Their total number is roughly 1.5 to 3 % of the total required publicly accessible charging points for battery-electric cars and LCV (compare section 5.3).

Table 7-1: Total zero emission infrastructure costs | Public use cases

Vehicle / propulsion types and use cases	**Costs [million Euro] per period**				
	until 2025	**2026-2030**	**2031-2035**	**2036-2040**	**TOTAL**
Cars & LCV | E	**274.8**	**917.7**	**795.2**	**617.1**	**2604.8**
Occasional/destination	152.6	795.5	742.0	572.8	2262.9
Range extension	122.2	122.2	53.2	44.3	341.9
Heavy duty vehicles | E	**95.9**	**98.1**	**57.6**	**18.9**	**270.5**
Range extension	95.9	98.1	57.6	18.9	270.5
Heavy duty vehicles | H2	**46.2**	**152.2**	**117.3**	**68.3**	**384.0**
Range extension	46.2	152.2	117.3	68.3	384.0
TOTAL	**416.9**	**1168.0**	**970.1**	**704.3**	**3259.3**

Source: Own calculations

Because the e-mobility market ramp-up is currently lagging behind compared to the underlying Transition Mobility Scenario *[26] [27] [28]* (refer to chapter 2), the demand projection for 2025 is likely to be overestimated. Thus, the growth rate between 2025 and 2040 will need to be accordingly steeper. Depending on how fast the market ramp-up can catch up with the target path, a temporal shift of the costs presented in Table 7-1 from the 2020s to the 2030s can be assumed.

7.1.3 Infrastructure costs for distribution and storage

The construction of electric charging points and H2 refuelling stations must go hand in hand with the expansion of the electricity and gas network as well as H2 storage capacities. H2 transportation by HDVs or train is not further discussed due to high uncertainty in terms of technological standards and costs. **H2 transport costs via pipeline** have been assessed at the European scale by van Rossum et al. (2022) in their report "European Hydrogen Backbone", covering H2 infrastructure costs required to support the pan-European H2 demand by 2040 for 28 countries. *[29]* According to their results, costs vary greatly between newly constructed versus repurposed pipelines, as well as between pipeline diameters. For newly constructed pipelines, average costs range between 1.5 million Euro per km for a small-diameter and 2.8 million Euro per km for a large-diameter pipeline. In contrast, repurposing an existing gas pipeline comes at lower average costs of between 0.3 and 0.5 million Euro per km. At the European scale, 60 % of the required H2 infrastructure in 2040 are assumed to consist of repurposed pipelines. Van Rossum et al. (2022) also provide cost estimates for compressor stations, ranging between 2.2 and 6.7 million EUR/MWe. For **H2 storage**, costs vary greatly depending on storage capacities and pressure levels of tanks. A questionnaire respondent estimated 500 Euro per kg H2 for a Type 1, 30 bar steel tank, and 1 000 Euro per kg H2 for a Type 4, 1 000 bar steel tank with carbon-fiber coating.

Electricity grid expansion costs per km are lower than H2 pipeline costs. According to a questionnaire respondent, costs for the lower grid level amount to about 200 000 Euro per km, whereas a survey for Oberösterreich revealed costs of 620 000 Euro per km for a 110 kilovolt overhead high voltage grid. *[57]*

7.1.4 Potentials for cost reduction

A number of synergies exist in infrastructure use that can keep the total costs of expanding the zero emission infrastructure in Austria low. First, the total public infrastructure costs in section 7.1.2 were calculated assuming that the following vehicle categories are able to use the same charging/refuelling infrastructure:

- E-cars and E-LCV
- E-HGV, E-coaches and E-service buses
- H2-HGV and H2-coaches

Second, building combined electric charging / H2-refuelling stations allowing vehicles with both propulsion types to recharge and refuel at the same location saves the costs of building a separate infrastructure for each. Third, costs can be reduced by locating the stations strategically such that they will be equally used by vehicles charging or refuelling by day and by night, thus ensuring a good overall utilization level. Fourth, a maximum expansion of private charging/refuelling infrastructure should be incentivised, especially of low-power charging in private homes. This not only reduces the number of publicly accessible charging/refuelling stations that need to be built, but it also mitigates the risk of public grid overload. In order to prevent the latter, peak load times with charging and fast-charging occurring simultaneously should also be avoided. Encouraging overnight charging for E-cars and origin/destination charging for E-HDV can help achieve this. Finally, spatial planning measures and a targeted management of traffic flows allow for an overall reduction in the required number of public stations.

7.2 Public support options for zero emission road traffic infrastructure development

7.2.1 Rationales for public support

From an economic perspective, several characteristics of the market for zero emission infrastructure and the vehicles that use it may justify state support. Zero emission vehicles and the necessary charging/refuelling infrastructure are closely linked in that consumer demand for zero emission vehicles depends crucially on comprehensive infrastructure supply – and vice versa. The two are therefore complementary and their markets highly interdependent. In effect, they can be seen as **two sides of the same market**, a market characterised by so-called **indirect network effects**. This means that the value of one good (e.g. zero emission infrastructure or zero emission vehicles) increases with the size of the market for the other good. Consequently, neither side of the market can fully develop without the other. Unless either achieves a certain critical size, a **“chicken and egg problem”** develops that hinders the establishment of the market in general. This problem has evidently been a barrier to the diffusion of zero emission mobility in the last decade.

Regarding zero emission infrastructure, one reason why private actors underinvest in its provision is its **high cost**. Building and running a network of charging/refuelling stations – especially if it should be nationwide and also cover less easily accessible or populated parts of the country – requires significant initial fixed capital investments, as well as (comparatively small) service costs to ensure operation and maintenance. As long as customers’ willingness to pay for using the infrastructure is below the average cost of supplying it, only very few private companies will enter the market. Like Tesla, they may attempt to cover their fixed costs by serving only a narrow customer segment with a higher willingness to pay. Tesla’s network coverage is exclusive to their cars and far from comprehensive. However, precisely when there is no comprehensive zero emission infrastructure network, **consumers' willingness to pay** is not high enough to cover the costs of private provision. *[21]* In addition, existing barriers to the adoption of zero emission vehicles – like high purchase cost and limited driving range – limit the number of potential users of the infrastructure. So overall, **expected profitability of the charging sites is low or even negative**, providing no incentive for private infrastructure providers to supply the market.

Especially in the early phase of technological development, constructing a zero emission mobility infrastructure network is also **very risky** for private operators because uncertainty is high as to which specifications will eventually be successful in the market. For example, several competing technologies still exist concerning propulsion (BEV vs. H2) and charging (e.g. CHAdeMO, CCS). Only recently, a consolidation process has begun to set in in response to consumer demand and international standardisation. Some of the early technological specifications will not survive this phase. Therefore, private infrastructure providers run the risk of incurring sunk costs by locking themselves into obsolete technology and may therefore decide not to enter the market in the first place.

Regarding zero emission vehicles, one reason why private actors have not sufficiently invested in their development according to economic theory – besides absent infrastructure, costs and risk – are so-called **technology spillovers**. These result from the public-good nature of technological knowledge, which, once developed, cannot be fully protected by its developers. Even if it enjoys patent protection, technological knowledge can be spread via informal channels such as developers changing jobs and reverse engineering. As a result, private actors cannot realise the full benefit of their investments in a new technology, part of which accrues to society at large. Since private companies take the decision how much to invest based on their private benefit – which in this case is below the full benefit to society – they under-invest in research and development (R&D). Hence, new technologies like zero emission vehicles are too slow to develop, unless public subsidies to R&D make up for the shortfall between private and social returns to investment in R&D. Another reason for the underdevelopment of zero emission vehicles is that the internal combustion engine has dominated mobility for so long that it has acquired significant market advantages compared to emerging technologies today, not least a fully established refuelling infrastructure. This creates a so-called **path dependency** in the direction of technological change, making the system inert and hindering the diffusion of zero emission vehicles.

Overall, the economic factors influencing private infrastructure providers' investment decisions (costs, consumer willingness to pay, profitability, risk) and the various market failures described above (network effects, technology spillovers, path dependency) can at worst **prevent the market for zero emission mobility from forming.** Given the Austrian government's commitment to meeting the climate targets set out in the Paris Agreement and the EU Climate Law, **public support is required** to ensure a timely expansion of public and private zero emission infrastructure.

Public support for the provision of charging/refuelling infrastructure improves the profitability of private companies' infrastructure investments and reduces their riskiness. This provides firms with an incentive to enter the market and consequently increases the size of the infrastructure network. But crucially, it also indirectly contributes to increasing the adoption of zero emission vehicles via the indirect network effect. Empirical evidence for the United States suggests that because of the strength of this effect, public subsidies for charging station deployment are even more cost-effective than subsidies for the purchase of electric vehicles. *[15]* These **feedbacks** imply that public support can remove some of the main barriers to market formation in the case of indirect network effects: Private suppliers of zero emission infrastructure only consider their own marginal benefit in their investment decision and do not take into account the benefit to the entire market (i.e. also on zero emission vehicles). Since public grants or subsidies increase the marginal benefit of infrastructure provision to private companies, they can help lift it up to the optimum level from the point of view of society as a whole. A further advantage of public intervention in zero emission infrastructure provision is that by steering infrastructure expansion, the state can influence the setting of compatible technology standards, thus avoiding an inefficient creation of parallel infrastructures.

7.2.2 Best-practice examples

In Europe, Norway and the Netherlands stand out as front-runners regarding the diffusion of zero emission mobility, particularly of battery-electric vehicles. Both countries boast (among) the highest shares of zero emission vehicles on the roads as well as the most extensive publicly accessible charging networks in Europe. In Norway, 65 % of all newly registered cars were BEV in 2021. *[45]* However, for various reasons, private home charging dominates publicly accessible charging. The Netherlands, on the other hand, has rapidly expanded its publicly accessible charging infrastructure since the early 2010s, especially at lower power categories. In 2021, the country had the most publicly accessible slow charging points in Europe. *[14]*

In **Norway**, the early, pre-market phase of the zero emission infrastructure ramp-up was characterised by national and local government involvement. From 2009, the state company Enova (previously Transnova) ***funded the initial construction costs*** of low-powered charging points across the country via ***direct grants*** to service providers. *[22]* Enova was founded in 2009 and is currently tasked with promoting the transition to sustainable energy production and consumption. It is affiliated to the Norwegian climate and environment ministry and is financed from state funds, among others a mandatory electricity duty. From the outset, the company had strong links to both the energy industry as well as local and regional authorities. In 2012, Enova also began to support the construction of fast chargers at a rate of 40 %, the first of which were free to use. From 2015 to 2018, Enova provided up to 100 % of funding for the installation of fast-charging points every 50 km along Norway's major roads, starting with rural places without charging point access. As a result, the country's fast-charging network fully covered the major roads by 2018. The contracts were awarded in four ***tender rounds*** to the lowest bidder. Private companies were increasingly involved in establishing the fast- and super-fast charging points, including fuel station and supermarket chains, energy providers, and companies like McDonalds and Ikea. *[11] [12] [22]*

At the same time, Norwegian municipalities and provinces also offered support programs. For example, the municipality of Oslo and others covered initial construction costs of charging points. From 2012 onwards, lower-powered charging points were installed and ***made available at no charge in some cities and towns***. This greatly helped diffusion, but it was also abused for free parking and was considered to have hindered private initiatives. In 2018, municipalities began to ***subcontract*** the operation of the charging points to private operators. Fast-charging infrastructure in cities has been a fully commercial market without public support since 2019. *[22]*

Finally, the Norwegian government's ***tax and subsidy policies for BEV*** themselves constituted an important complement to infrastructure roll-out for fostering the diffusion of zero emission mobility. An exemption from registration tax for BEV has existed since 1991; since 2001, BEV have also been exempt from value-added tax (VAT). From the late 1990s until 2018, BEV owners did not have to pay road tolls, ferry and parking fees (since then, they pay up to 50%). *[22]* In addition, local authorities have provided public support to incentivise the installation of home chargers in private apartment buildings and parking spaces. *[11]*

In the **Netherlands**, the early roll-out of publicly accessible charging infrastructure was ***subsidised*** by the national government until 2013. Local and regional authorities applied for a charging point with EVnetNL, a foundation established on initiative of Dutch power network operators, which took care of installations. BEV propulsionrs were also able to request charging points near their home in participating municipalities (this is still possible in many municipalities, and the charging point application and installation are still free).

[13] To accelerate the scale-up of charging infrastructure, the national government created so-called ***focus areas*** in 2011, including metropolitan regions and cities, but also more remote areas as well as border regions. Supported by national government subsidies, these focus areas were to identify and collaborate with local partners for rolling out charging infrastructure, such as companies and knowledge institutes. ***Tenders*** for charging station installation were handled by EVnetNL, now renamed ElaadNL, which continued to manage the existing publicly accessible charging station network it had previously built. *[18]*

In 2016, a consolidation and commercialisation phase set in. To improve the business case for private companies to build and run charging stations, the National Charging Infrastructure Knowledge Platform (NKL) was set up. Its purpose has been to ***develop and disseminate research aimed at lowering costs***, e.g. by optimising the installation process, and hence create opportunities for private companies to enter the market for charging infrastructure. The NKL is once again a collaborative initiative, involving network and charging point operators, charging point producers, knowledge institutions and municipalities. *[19] [60] [61]* Eventually, the Netherlands were the first European country to enable commercial exploitation of charging stations along the entire motorway network. *[19]* In addition to this strong focus on ***public-private partnerships***, regional and local authorities have continued to play an important role in setting up the Netherland's dense charging network. Examples include ***public procurement*** of zero emission public transport service buses as well as public tenders for private companies to install and operate charging points in North Brabant and funding the installation of publicly accessible fast-charging infrastructure as well as incentives for the purchase of electric vehicles in Amsterdam. *[18] [62]*

7.2.3 Conclusions on public support options

Overall, the examples of Norway and the Netherlands illustrate that **long-term collaborations** between national as well as regional and local tiers of government, private companies, power grid operators and institutions that generate and disseminate expertise are important ingredients to a successful diffusion of zero emission infrastructure. In the early stage of zero emission infrastructure roll-out, **government involvement is crucial** for overcoming the "chicken-and-egg" problem characterising the diffusion of zero emission mobility. Public funding – via incentives such as direct grants, subsidies, tendered projects or public procurement – helps to remove some of the barriers to the adoption of zero emission mobility that are created by the indirect network effect and other externalities described in section 7.2.1. Once the market for zero emission mobility has reached a critical size and viable business models for private actors emerge, state involvement can be reduced. In addition, as the Norwegian but especially the Dutch focus on public-private partnerships shows, **collaboration with and creating a business case for companies** early on is key for establishing viable business models, so that private actors can take over the market once it has been established. This has proven easier for the higher-powered charging infrastructure, since consumer willingness to pay tends to be higher for faster charging as it represents a better service. Lower-powered publicly accessible charging points present less of a business case to operators because of the high cost of the infrastructure and the low marginal cost of energy that vehicles charge. *[11]*

A strong role for **regional and municipal authorities** from the start is also essential in order to draw on knowledge available locally and to take into account the communities' needs, thereby getting them on board. For the reasons laid out in the previous paragraph, devolving (parts of the) implementation of the infrastructure roll-out to lower tiers of government makes the most sense for lower-powered charging stations in towns and cities, as has been the case in Norway and the Netherlands. Finally, **institutional knowledge platforms** such as NKL in the Netherlands provide a space for exchange and serve the function of knowledge multiplier.

Regarding focus areas for infrastructure roll-out, one focus of public support programmes should be on expanding the **publicly accessible fast-charging network** along motorways and federal roads. Since fast-charging for range extension enables longer trips, it is key to spurring the adoption of zero emission vehicles by taking away consumers' "range anxiety". A second focus should be on ramping up the number of **publicly accessible charging points for occasional/destination charging** in towns, cities and less well-connected areas, which are crucial for encouraging the take-up of zero emission mobility among consumers without private charging access at home or at work. Thirdly, **government incentives for private home infrastructure installation as well as zero emission vehicle purchase** are an important complement to infrastructure roll-out in order to foster the diffusion of zero emission mobility. Good examples from Norway include subsidies for home charging infrastructure and tax exemptions to zero emission vehicle purchase.

8 MARKET ANALYSIS EVALUATING THE NEED FOR PUBLIC SUPPORT

The transition of road traffic to emission-free vehicles is a core objective of the European Green Deal. The availability of sufficient charging infrastructure is a prerequisite for the market penetration of zero emission vehicles. In order to achieve the required growth rates of electric vehicle fleets, infrastructure related obstacles must be removed. Therefore, especially in the next years it will be necessary to proactively expand zero emission infrastructure at an even higher pace compared to the rise of charging demand. For all EU member states, it is of highest priority to outline a path towards the achievement of the ambitious infrastructure development goals, based on the countries' current stage of development as well as individual opportunities and challenges. *[25] [39]*

Considering the time sensitivity of the development tasks, reliable knowledge about the potential impact of public aid programs is sought by the responsible policy makers. Chapter 7 described different public support and funding options. A key question for decision making is to which extent the formation of a functioning market could succeed within the given time limits without public intervention. The present evaluation therefore reviews the infrastructure demand forecast derived in chapter 5 and assesses the current state of expansion and potential of the market.

8.1 Gap analysis

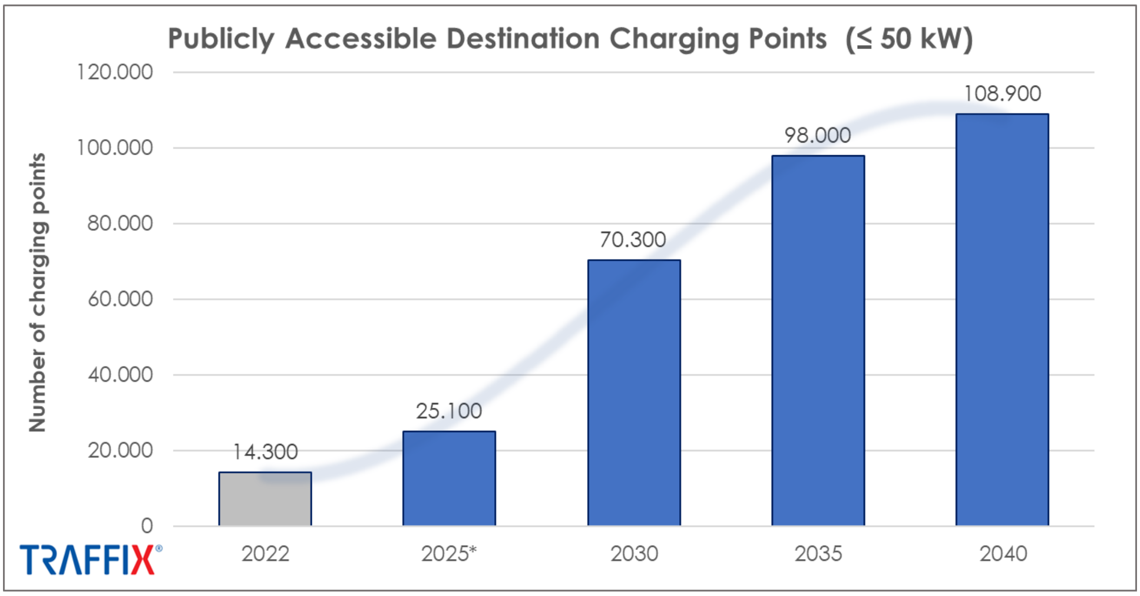
All publicly accessible charging points in Austria are registered in the E-Control Ladestellenverzeichnis. The underlying dataset has been provided by Austriatech *[2]* for the use in GREENROAD. **Currently**, there are about **15 000 publicly accessible charging points** available in Austria (approx. **14 300 destination and 700 range extension** charging points according to the GREENROAD use case definition). According to the underlying scenario (see chapter 2), EV growth rates are expected to accelerate significantly in the next years. GREENROAD results show that **by 2040** a total number of around **113 000 publicly accessible charging points** for cars and light commercial vehicles (thereof approx. **109 000 destination** and nearly **4 000 range extension** charging points) will be required (see Figure 8-1 and Figure 8-2). Hence, based on the current state in 2022, the **expansion factors required** to reach the projected numbers are **4.9** (2030) and **7.6** (2040) **for destination charging** respectively **5.4** (2030) and **5.6** (2040) **for range extension charging**.

For the assessment of the required expansion speed, a comparison with the network expansion during the last two years has been conducted. For the use case **destination**

charging, about 3 200 additional charging points per year have been implemented between early 2021 and early 2023. This **expansion speed has to be more than doubled to around 7 000 charging points per year** in order to reach the projected demand in 2030. Between 2030 and 2040 around 3 900 additional charging points per year are sufficient. For the use case **range extension**, the expansion speed between early 2021 and early 2023 amounts to around 500 charging points per year. From a national perspective, a growth rate of **400 high-power charging points per year until 2030** would be sufficient, but with the addition of keeping the required geographical coverage in mind. Between 2030 and 2040, due to the occurring saturation effect around 10 additional high-power charging points per year are sufficient.

For the HDV sector no gap analysis was conducted because there are de facto no existing charging stations available at the moment. The general findings presented in chapter 8 apply analogously for heavy duty vehicle infrastructure.

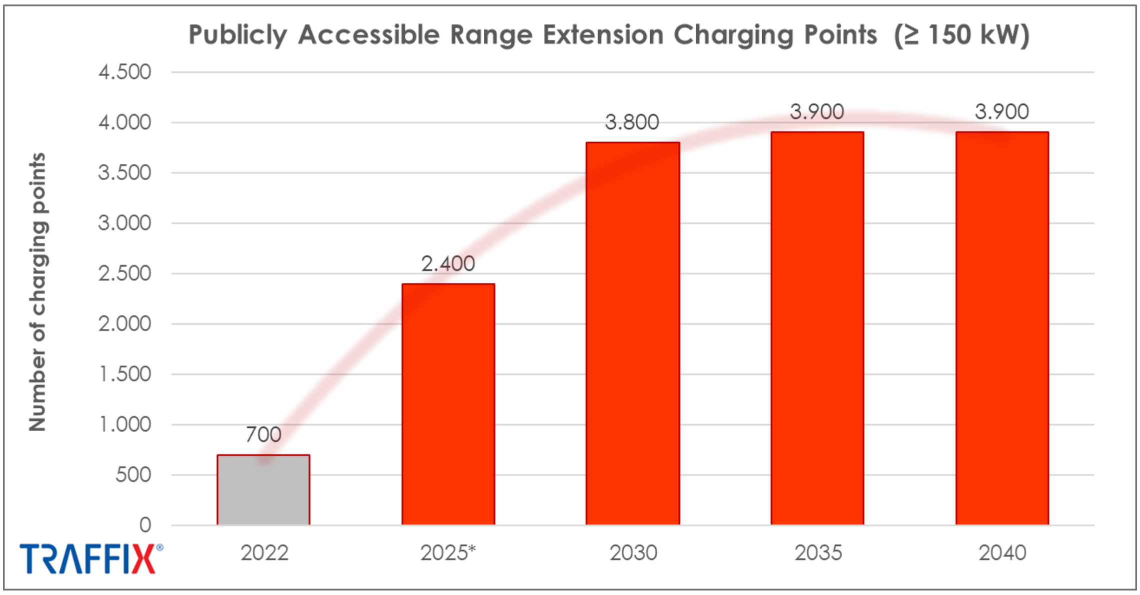
Figure 8-1: Publicly accessible destination charging | Existing charging points and projected demand



Note: Because the e-mobility market ramp-up is currently lagging behind compared to the underlying Transition Mobility Scenario *[26] [27] [28]* (refer to chapter 2), the demand projection for 2025 is likely to be overestimated. Thus, the growth rate between 2025 and 2040 will need to be accordingly steeper.

Source: GREENROAD forecast model (see chapter 5), E-Control Ladestellenverzeichnis (Q3/2022) *[2]*

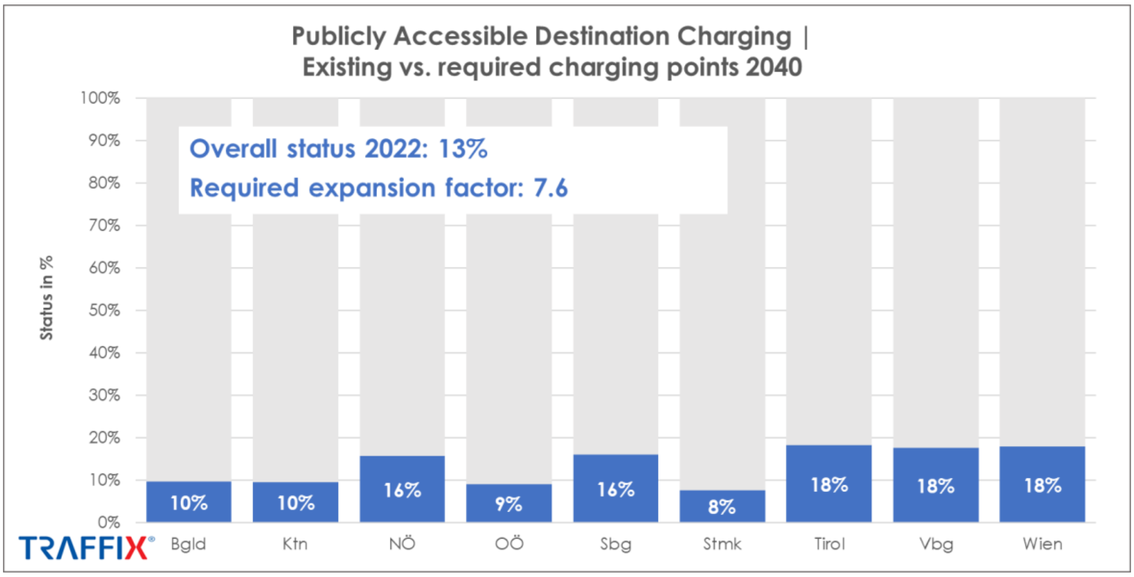
Figure 8-2: Publicly accessible range extension charging | Existing charging points and projected demand



Note: Because the e-mobility market ramp-up is currently lagging behind compared to the underlying Transition Mobility Scenario [26] [27] [28] (refer to chapter 2), the demand projection for 2025 is likely to be overestimated. Thus, the growth rate between 2025 and 2040 will need to be accordingly steeper.

Source: GREENROAD forecast model (see chapter 5), E-Control Ladestellenverzeichnis (Q3/2022) *[2]*

Figure 8-3: Publicly accessible destination charging | Gap analysis 2022-2040 by federal state

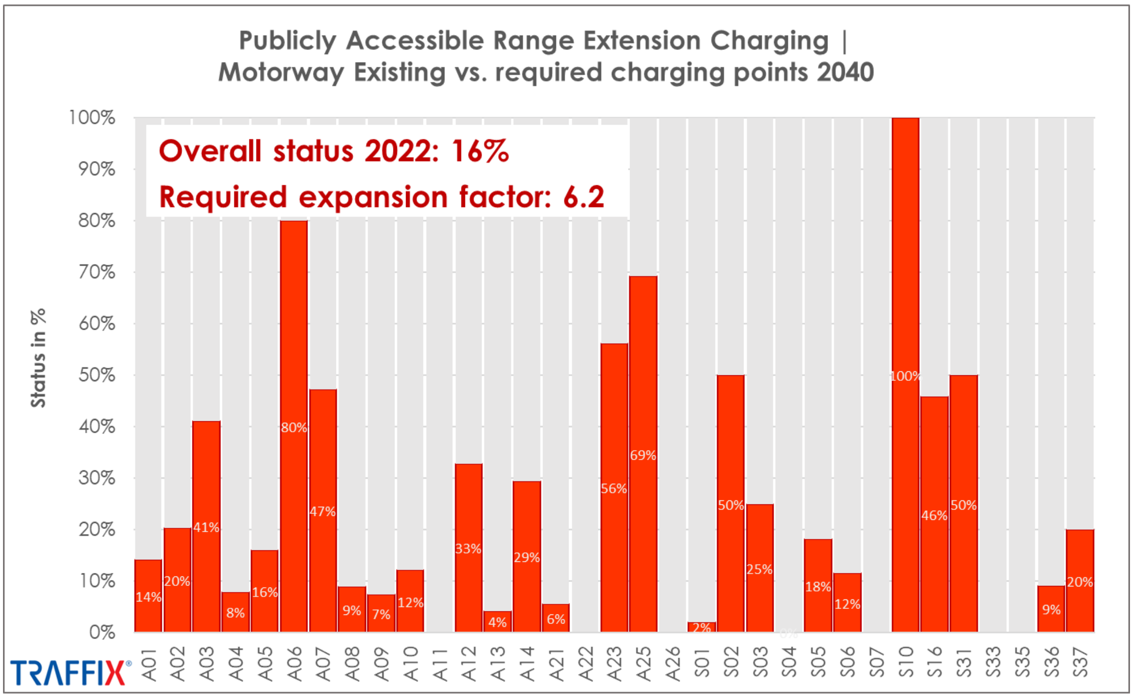


Source: GREENROAD forecast model (see chapter 5), E-Control Ladestellenverzeichnis (Q3/2022) *[2]*

Figure 8-3 shows a regional gap analysis regarding publicly accessible destination charging points by federal state. Comparing the existing number of charging points in 2022 vs. the projected requirements in 2040, the **current overall expansion status** is **13 %** with the lowest being 8 % in Steiermark and the highest being 18 % in Wien, Tirol and Vorarlberg. In total, the number of publicly accessible destination charging points must be expanded by the factor of 7.6 until 2040.

Figure 8-4 illustrates the regional gap analysis regarding publicly accessible range extension charging along the Austrian motorways. For the analysis all existing range extension charging locations (according to the Ladestellenverzeichnis *[2]* and classified in line with the use cases defined in GREENROAD, refer to chapter 5) within a distance of 1 500 m around motorways have been considered. Comparing the existing number of charging points in 2022 vs. the projected requirements in 2040, the **current overall expansion status** is **16 %**. Accordingly, the total number of range extension charging points along motorways must be expanded by the factor of 6.2 until 2040. The gap analysis regarding publicly accessible range extension charging points at off-motorway locations (> 1500 m to motorways, see Figure 8-5) shows a **current overall expansion status** of **27 %** and an according expansion factor of 3.7 until 2040.

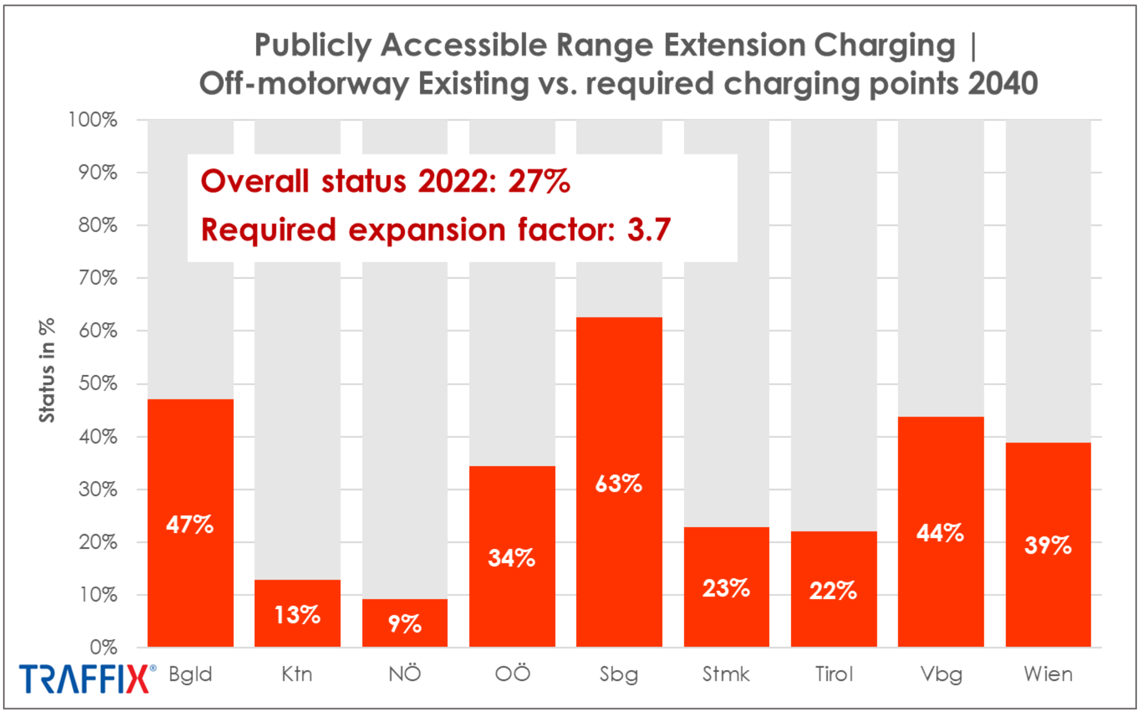
Figure 8-4: Publicly accessible range extension charging | Gap analysis 2022-2040 by motorway



Note: Analysis referred to locations on or in close proximity (1500 m) to motorways

Source: GREENROAD forecast model (see chapter 5), E-Control Ladestellenverzeichnis (Q3/2022) *[2]*

Figure 8-5: Publicly accessible range extension charging | Gap analysis 2022-2040 by federal state



Note: Analysis referred to locations on or in close proximity (1500 m) to motorways

Source: GREENROAD forecast model (see chapter 5), E-Control Ladestellenverzeichnis (Q3/2022) *[2]*

8.2 Status-quo: First-mover phase

The Austrian charging infrastructure is still in an early stage of development. While individual organisations can find this sentiment opportunistic and might detect specific first-mover advantages the market dynamics don't reach a sufficient rate yet due to the high risks stakeholders are exposed to. Charging infrastructure must meet the latest technical standards while charging technology is developing rapidly with frequent innovations. Permanent operation and maintenance must be ensured for public infrastructure. Because generally high investments are necessary for the development of charging infrastructure (as described in chapter 7) economic profitability of charging sites is crucial for operators. However, especially in the early stages of operation, charge point operators are facing the risk of insufficient utilization. For these reasons yet no functioning market is forming and infrastructure is not expected to be deployed at a sufficient rate on commercial terms.

8.3 Conclusion regarding need for public intervention

Without public support, market operators cannot be expected to take on the economic risk, remedy the current inadequacy of recharging infrastructure and ensure that new charging infrastructure meets the necessary technical standards and geographical coverage. The results of GREENROAD clearly show an urgent need for public fundings to accelerate the market ramp-up and support the development of charging infrastructure at the required pace. Such fundings can reduce investment costs and economic risks and will therefore have substantial incentive effects as the beneficiaries would not make the required investments without public support.

9 RECOMMENDATIONS FOR ACTION

The electrification of road traffic in Austria is among others a key element to achieve the 2040 climate targets. It is an enormous challenge and can only be accomplished with effective underlying measures. Available sources of renewable energy are limited. The overall priority must be to reduce the overall demand for road traffic by promoting the modal shift to public transport and active mobility and to increase efficiency by means of sharing mobility and digitalisation. Ambitious action towards these targets forms the foundation that makes a complete electrification of road traffic by 2040 possible.

With a view to a complete electrification of road traffic by 2040, the following technology-mix is recommended:

- Car and LCV: BEV
- Heavy duty vehicles (solo truck, semitrailer, coach): Predominantly BEV, complemented by hydrogen FCEV (optionally complemented by ERS)
- Service bus: BEV

The investigations carried out as part of the present research project have shown that, in addition to the necessary modal shift according to the goals of the National Mobility Masterplan 2030 *[4]*, an intensive expansion of renewable energies in Austria is also of central importance for achieving climate neutrality in traffic. The speed at which this can be achieved depends on the type, intensity and point in time of the bundle of push and pull measures implemented by politicians.

The results calculated with the GREENROAD zero emission infrastructure projection model show a substantial need for expansion of zero emission charging and refuelling infrastructure, whereby there are significant differences between use cases as well as on regional level. The projected numbers by vehicle category are summarized in the following subsections 9.1 to 9.3. A general aspect that has to be emphasized is that the temporal growth rates required for infrastructure expansion look quite different depending on the charging use case. Especially interesting is the fact that **for high-power range extension charging**, the **peak of required charging points** is already expected **in the early 2030s**. After that, there occurs a **saturation effect** and the demand for fast range extension charging remains relatively stable until (and after) 2040. This is caused by increasing average battery ranges and the fact that, considering higher costs and negative impacts on battery lifetime, fast charging stations will only be used when necessary.

Because the e-mobility market ramp-up is currently lagging behind compared to the transition scenarios *[26] [27] [28]* that are an essential input to the GREENROAD projection model, the demand projection for 2025 is likely to be overestimated. Thus, the growth rate between 2025 and 2040 will need to be accordingly steeper. Considering this **urgent need for action**, a central conclusion of the study is that a **public market intervention in the form of financial fundings for zero emission infrastructure is inevitable**. During the completion phase of the present study, an important step has already been implemented by the launch of the ENIN funding program *[51]* in early 2023. Moreover, in late 2022 a national centre for e-mobility called OLE *[34]* started operations. OLE has the mission to coordinate and manage all relevant activities for the expansion of charging infrastructure in Austria. It provides support for all relevant stakeholders and collects data for monitoring the development.

In addition to the expansion of charging infrastructure, it is important to expand daily storage for renewable energy as well as seasonal energy storage options to avoid excess energy in summer. Furthermore, it has become evident that the required expertise and workforce are currently not available to the necessary extent. In order to foster a rapid infrastructure expansion, appropriate educational and labour market measures have to be taken.

The following chapters outline the future infrastructure requirements derived by the GREENROAD projection model and summarize specific recommendations for action structured by the main vehicle categories.

9.1 Cars and light commercial vehicles

9.1.1 Private charging: Home, workplace and business premises

Based on the modelled charging demand nearly **2.3 million private charging points** are required **by 2030** and nearly **4.4 million by 2040** in Austria's private homes, at workplaces and at business premises for light commercial vehicles. The results of the GREENROAD projection model provide detailed information on municipality level. As reliable figures on the existing number of private charging stations – both at home and at work – are missing, a registration obligation could help to generate data on those numbers.

The construction of charging stations for tenants of apartment buildings needs to be simplified. Although amendments in the Austrian housing law have been implemented, they do not yet have the desired effect. Research is being conducted into how further improvements can be made. The technical restrictions for grid access, due to many charging stations within one building or an already high connection utilization hinders many construction plans. Necessary grid connection reinforcement often comes with high construction costs and significant bureaucratic obstacles. Due to missing regulations concerning load-management in multi-tenant buildings, unfair situations are leading to conflicts, which in turn hinder new projects.

In Vienna, the legal requirement for the construction of charging stations during building construction or retrofitting is insufficient and should be amended. State law in Niederösterreich, for example, requires the provision of electric infrastructure with a defined charging power for each parking space in specific residential buildings. In Vienna on the other hand, state law merely requires the construction of empty piping, but no provisions for charging power are made. Since the subsequent reinforcement of the building grid connection is costly, it is suggested to add requirements for charging power to the Vienna Garage Act (Wiener Garagengesetz).

One of the most important tools in maintaining a stable grid and therefore supporting electricity grid operators, is the implementation of variable electricity tariffs. These tariffs support adapting energy prices according to the current grid situation. Therefore, an incentive is created for dynamic charging, which results in electric vehicles charging late at night, when energy prices and grid utilization are low. This requires the standardization of communication standards like ISO 15118 or the OCCP 2.0. For both, charging at home and at the workplace the introduction of tools to simplify the billing modalities and related processes would certainly be beneficial.

Workplace charging for employees has the benefit of being available for the consumption of renewable and inexpensive photovoltaic energy during the day. The mentioned communication standards also support future vehicle-to-grid applications. This strategy uses electric vehicles as energy storage devices, with different possible business models. Workplace charging frequently benefits from an existing high-capacity grid connection and oftentimes large roof surfaces, supporting large PV-plants and charging stations. Therefore, a focus should be put on promoting this easy-to-implement possibility.

9.1.2 Publicly accessible charging: Occasional/destination and range extension

Based on the modelled charging demand approx. **70 300 destination** and **3 800** high-power **range extension charging points** are required in Austria **by 2030** respectively

108 900 destination and **3 900 range extension charging points by 2040**. Based on the current state in 2022, the **expansion factors** required to reach the projected numbers are **4.9** (2030) and **7.6** (2040) for destination charging respectively **5.4** (2030) and **5.6** (2040) for range extension charging. The results of the GREENROAD projection model provide detailed information on regional level as well as per section of the motorway network. According to the model results, the demand **peak for high-power range extension charging** is already expected **in the early 2030s**. After that, there occurs a saturation effect and the demand for fast range extension charging remains relatively stable until (and after) 2040. Therefore, **the majority of the required high-power range extension charging points should already be built until 2030** in order to prevent further delays of the e-mobility market ramp-up.

Grid connections of large or high-power charging stations should be simplified or grid operators obligated to establish connections. A similar platform as the German "Flächen-TOOL" for Austria, ideally also integrating the information about the available connection to the electric grid, could facilitate the construction of charging infrastructure. As the current regulation does not allow the sale of energy at highway-service stations besides the concession owner, an amendment needs to be made, to support the development of charging stations. Owners of semi-publicly accessible locations such as parking lots of supermarkets or hospitals should be informed about the business opportunities of overnight parking and charging outside of opening hours.

To account for the growing number of electric commercial vehicles, publicly accessible charging stations and especially charging parks need to support large vehicles in terms of dimensions and charging power. These charging parks should be situated at locations with favourable grid connection and should also be equipped with energy storage, PV-production, hospitality and rest facilities. For this, also adaptations need to be made in the zoning plans. Analogous to gas stations, charging parks should be signposted for easier discoverability. Charging prices, current occupancy and technical equipment should be made public at the location and online.

Currently there exist several complex billing schemes for publicly accessible charging points which are partially time-based. To accelerate the installation of fast charging stations, the adoption of an obligatory, standardized and calibrated billing scheme is urgently needed. This includes two main subjects: First, the introduction of simple tariffs which are ideally not based on charging time but charging energy and ensure interoperability between station operators with low or no roaming fees at all and second, easy accessibility for occasional users who do not hold a charging card through direct payment options at the charging stations.

9.2 Heavy Duty vehicles

9.2.1 Business premises

Based on the modelled charging demand approx. **24 400 private charging points** are required **by 2030** and **32 300 by 2040** at business premises in Austria for heavy duty vehicles like solo trucks, semitrailers and coaches. The results of the GREENROAD projection model provide detailed information on regional level.

In certain applications, especially with high loads or very long transport distances, H2 technology offers advantages compared to battery electric trucks, semitrailers and coaches. Based on the percentage shares between BEV and H2 technology in the HDV sector derived by the underlying energy scenarios *[26] [27] [28]*, the model results project a requirement of nearly **200 private H2 refuelling points** at business premises **by 2030** and approx. **800 by 2040**. As the development of H2 vehicles, storage and fuelling technology is still lacking behind compared to the BEV sector and larger H2 vehicle fleets will only emerge after 2030, a significant acceleration of growth is expected during the 2030s. It can be assumed that especially pioneer fleet operators and larger transport operators predominantly will build their own private infrastructure.

9.2.2 Public range extension

Based on the modelled charging demand approx. **1 400 publicly accessible HDV charging points** are required **by 2030** and **1 600 by 2040** in Austria for heavy goods vehicles and coaches. Thereof, around **70 %** should be **overnight-chargers** with approx. 150 kW and **30 %** so-called **megawatt chargers**. The results of the GREENROAD projection model provide detailed information on regional level as well as per section of the motorway network. Like for cars and light commercial vehicles, the demand **peak for high-power range extension charging** is already expected **during the 2030s**. After that, there occurs a saturation effect and the demand for publicly accessible HDV charging remains relatively stable until (and after) 2040. Therefore, **the majority of the required publicly accessible HDV charging points should already be built until 2030** in order to prevent further delays of the e-mobility market ramp-up.

Regarding hydrogen technology, the results anticipate a requirement of around **70 publicly accessible H2 refuelling points by 2030** and **130 by 2040**. As larger H2 vehicle fleets are not likely to emerge before 2030 and especially pioneer fleet operators and larger transport operators predominantly will build their own private infrastructure, at the moment the pressure on the publicly accessible H2 refuelling infrastructure is not as crucial as for the electric charging infrastructure. The principal objective is to offer a basic refuelling infrastructure in line with the European development goals especially along the TEN-axes. It is strongly recommended to develop consistent technical standards for the construction of hydrogen filling stations. These standards should not differ between the Austrian federal states and should be developed in close conjunction with EU-wide developments. Also, a coordination body for hydrogen corridors in Europe should be established.

As a general recommendation, politics should think about in time what implications an increasing number of zero emission trucks will have on the toll system and on the general financing system for maintenance of motorways in Austria.

Excursus: Electric road systems

The R&D project Energy Roads *[1]* examined the feasibility of an electric road system (ERS) using an overhead line for dynamic charging of heavy vehicles. According to this study, for potential users and vehicle manufacturers the technology will only be of interest with a certain prospect of a growing network throughout Europe. Thus, a possible future realization of ERS depends on the prerequisite of a clear political commitment to a widespread roll out of a standardized infrastructure to gain momentum in the development. At the moment it is still unclear which role electric road systems will actually play in the long term. In the event that selected motorway sections along the TEN-T network will be equipped with ERS, the projected number of required HDV charging points could be reduced to a certain degree.

9.3 Public transport service buses

Based on the modelled charging demand around **1 300 charging points** are required **by 2030** and **1 900 by 2040** for public service buses. It is assumed that these charging points will be deployed and operated by the respective authorities. The main locations for these charging points are expected to be bus depots (mainly for overnight charging) on the one hand and relevant stations of the public transport networks (mainly for recharging during the day) on the other hand.

9.4 E-Bikes

9.4.1 Private charging: Home and workplace

It is recommended to introduce technical requirements for the quality of bike parking facilities, including charging facilities, in residential buildings in the building regulations of the federal states. Employees should be informed about available subsidies for work-bikes. Additional subsidies for bike infrastructure at the workplace would make the use of bikes more practical (e.g. storage lockers, charging stations etc.)

9.4.2 Publicly accessible charging

A technical standard for plug connectors for e-bike charging needs to be introduced – and / or publicly accessible charging stations for e-bikes need to be developed that take into account the difficulty of 230 V sockets in public space. To support the development of e-bikes for commercial uses, publicly accessible charging infrastructure needs to be further reinforced. Most important for the use as last-mile transport vehicle and intermodal transport is charging and safe storage infrastructure at mobility hubs. At train-stations e-bikes must be stored at weatherproof, secure spaces with a possibility of charging. Rentable lockers for bike equipment like weather-proof clothes and helmets would make the use even more attractive. As with electric cars, implementing a standardized charging and billing system is necessary for commercial solutions to thrive.

LIST OF ABBREVIATIONS

A	Autobahn
A+S	Austrian highway network
AC	alternating current
AFID	Alternative Fuels Infrastructure Directive
approx.	approximately
BEV	battery electric vehicles
BEV	Bundesamt für Eich- und Vermessungswesen
Bgld	Burgenland
C	Celsius
CCS	Combined Charging System
CHAdeMO	Charge de Move
CO2	carbon dioxide
DC	direct current
Dseg	demand segment
DSO	distribution system operator
E	electric
e.g.	for example
ENIN	Emissionsfreie Nutzfahrzeuge und Infrastruktur (funding program by the Austrian Research Promotion Agency FFG)
ERS	electric road systems
etc.	et cetera
EU	European Union
EV	electric vehicle
FCEV	fuel cell electric vehicles
GHG	greenhouse gases
H2	hydrogen
HDV	heavy duty vehicles
HGV	heavy goods vehicles
i.e.	that is
ISO	International Organization for Standardization
kg	kilogram

km	kilometres
Ktn	Kärnten
kW	kilowatt
kWh	kilowatt hours
kV	kilovolt
LCV	light commercial vehicles
LoI	letter of intent
Maas	Mobility as a service
m	metres
m^2	square metres
min	minute(s)
MFH	multi-family homes
MW	megawatts
MWe	megawatts electric
MWh	megawatt hours
NKL	National Charging Infrastructure Knowledge Platform (Netherlands)
No.	number
NÖ	Niederösterreich
OCCP	Open Charge Point Protocol
OD	origin-destination
OLE	Österreichs Leitstelle für Elektromobilität
OLI	Österreichische Luftschadstoff-Inventur (Austrian Air Pollutant Inventory)
OÖ	Oberösterreich
PJ	petajoule
POI	points of interest
PV	photovoltaics
RFNBOs	renewable liquid and gaseous fuels of non-biological origin
R&D	research and development
S	Schnellstraße
SAF	Sustainable Aviation Fuels
Sbg	Salzburg
SFH	single-family homes
SMF	Sustainable marine fuels

Stmk	Steiermark
TEN-T	Trans-European Transport Network
TJ	terajoule
UNFCCC	United Nations Framework Convention on Climate Change
V	volt
VAT	value-added tax
Vbg	Vorarlberg
vs.	versus
v.v.	vice versa
vkm	vehicle kilometres
VMÖ	Verkehrsmodell Österreich (Austrian National Traffic Model)
WEM	with existing measures
WP	work package
ZEI	zero emission infrastructure

BIBLIOGRAPHY

[1] Austrian Energy Agency, BVe, Trafility, IKK (2021): EnergyRoads | Put trucks on a leash: Feasibility, meaningfulness, acceptance and implementation of on-trip truck charging in Austria | 2021 → https://projekte.ffg.at/projekt/4032443

[2] Austriatech (2022): Ladestellenverzeichnis | GIS-Daten | November 2022

[3] Bauer S. et al. (2017): Underground Sun Storage | Endbericht 2017 → https://www.underground-sun-storage.at/fileadmin/bilder/SUNSTORAGE/Publikationen/UndergroundSunStorage_Publizierbarer_Endbericht_3.1_web.pdf

[4] Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie (BMK): Austria's 2030 Mobility Master Plan | Realigning the mobility sector → https://www.bmk.gv.at/en/topics/mobility/mobilitymasterplan2030.html | 10.11.2022

[5] Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie (BMK): Elektromobilität in Österreich – Zahlen, Daten & Fakten | Juli 2022, Wien → https://www.bmk.gv.at/themen/mobilitaet/alternative_verkehrskonzepte/elektromobilitaet/zahlen/oesterreich.html | 04.11.2022

[6] Hüttler W., Amann C., Lampersberger P., Fidler P. (2017): Nachrüstung von Ladestationen in bestehenden großvolumigen Wohngebäuden → https://e-sieben.at/publikationen/17036_e-Mob/17036_Studie_Nachruestung_von_Ladestationen.pdf?m=1570187417& | 04.11.2022

[7] Kern T., Dossow P., Morlock E. (2022): Revenue opportunities by integrating combined vehicle-to-home and vehicle-to-grid applications in smart homes | Applied Energy 307 | 2022 → https://www.sciencedirect.com/science/article/pii/S0306261921014586

[8] Lehtola T., Zahedi A. et al. (2021): Electric vehicle battery cell cycle aging in vehicle to grid operations: A review |2021 → https://ieeexplore.ieee.org/document/8936355

[9] Preßmair G., Lampersberger P. (2020): E-Mobilität in Wohnhausanlangen – Technische Herausforderungen und Möglichkeiten | in: immolex November 2020 → https://www.e-sieben.at/publikationen/E_Mobilitaet/immolex_2020-11_342_Guntram_Pressmair.pdf?m=1610369648&

[10] Fan L., Tu Z., Chan S. (2021): Recent development of hydrogen and fuel cell technologies: A review | 2021 https://www.sciencedirect.com/science/article/pii/S2352484721006053

[11] Figenbaum E. (2018): Electromobility status in Norway: Mastering long distances – the last hurdle to mass adoption | Institute of Transport Economics | TOI report 1627/2018 → https://trid.trb.org/view/1509475

[12] Figenbaum E. (2019): Norwegian EV charging: Infrastructure and user experiences | Institute of Transport Economics | Webinar presentation 2019 →

https://www.nationalacademies.org/documents/embed/link/LF2255DA3DD1C41C0A42D3BEF0989ACAECE3053A6A9B/file/DCDBC621E1BE55C366D3F8EB2522C002E5D542B77B86?noSaveAs=1

[13] Helmus J. et al. (2018): Assessment of public charging infrastructure push and pull rollout strategies: The case of the Netherlands | Energy Policy | 2018 → https://www.sciencedirect.com/science/article/abs/pii/S0301421518303999

[14] International Energy Agency (2022): Global EV Outlook 2022 → https://www.iea.org/reports/global-ev-outlook-2022

[15] Li S. et al. (2016): The market for electric vehicles: indirect network effects and policy design, Journal of the Association of Environmental and Resource Economics |2016 → https://www.journals.uchicago.edu/doi/full/10.1086/689702

[16] Ligen Y., Vrubel H., Girault H. (2018): Mobility from renewable Electricity: Infrastructure Comparison for battery and hydrogen fuel cell vehicles | 2018 → https://www.mdpi.com/2032-6653/9/1/3

[17] Lohse D. et al (2006): Ein zweiseitig gekoppeltes Modell zur simultanen Berechnung der Verkehrserzeugung, Verkehrsverteilung und Verkehrsaufteilung | Theoretischer Hintergrund und praktische Anwendung für ein nationales Modell der Schweiz → https://www.research-collection.ethz.ch/bitstream/handle/20.500.11850/39448/eth-28883-01.pdf?sequence=1%5C046isAllowed=y

[18] Netherlands Enterprise Agency (RVO) (2011): Electric mobility gets up to speed: 2011-2015 Action Plan | 2011 → https://www.rvo.nl/sites/default/files/bijlagen/Action%20Plan%20English.pdf

[19] Netherlands Ministry of Economic Affairs (2016): Electric Transport Green Deal 2016-2020 | 2016 → https://www.greendeals.nl/sites/default/files/downloads/Green-Deal-Electric-Transport-2016-2020.pdf

[20] Previati G., Mastinu G., Gobbi M. (2022): Thermal Management of Electrified Vehicles – A Review | Energies 2022 → https://www.mdpi.com/1996-1073/15/4/1326

[21] Reinke J. (2014): Bereitstellung öffentlicher Ladeinfrastruktur – Eine institutionenökonomische Analyse | 2014 → https://api-depositonce.tu-berlin.de/server/api/core/bitstreams/960eb215-b6ea-4955-a4e5-47a96757c0e8/content

[22] Schulz F., Rode J. (2022): Public charging infrastructure and electric vehicles in Norway | Energy Policy, 2022 → https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3931394

[23] Schwendinger M. (2022): Infrastruktur für erdölfreien Lkw-Verkehr planen | VCÖ-Factsheet, 2022 → https://vcoe.at/publikationen/vcoe-factsheets/detail/infrastruktur-fuer-erdoelfreien-lkw-verkehr-planen

[24] Singh A. (2016): Electric Road Systems: A feasibility study investigating a possible future of road transportation | 2016 → http://kth.diva-portal.org/smash/record.jsf?pid=diva2%3A1046753&dswid=2247

[25] SMATRICS GmbH & Co KG: Masterplan Ladeinfrastruktur 2030 | Wien 2022 → https://smatrics.com/sites/default/files/smatrics-masterplan-ladeinfrastruktur-2030.pdf

[26] Umweltbundesamt (2017): Energie- und Treibhausgas-Szenarien im Hinblick auf 2030 und 2050 | Synthesebericht 2017 | Wien 2017 → https://www.umweltbundesamt.at/fileadmin/site/publikationen/rep0628.pdf

[27] Umweltbundesamt (2020): Pathways to a zero carbon transport sector | Final Report 2020 → https://www.klimafonds.gv.at/wp-content/uploads/sites/16/P2ZCT_Ergebnisbericht-002.pdf

[28] Umweltbundesamt (2022): Transition Mobility 2040 | Entwicklung eines Klima- und Energieszenarios zur Abbildung von Klimaneutralität im Verkehr 2040 | Wien 2022 → https://www.umweltbundesamt.at/fileadmin/site/publikationen/rep0808.pdf

[29] Van Rossum R., Jaro J., La Guardia G., Wang, A., Kühnen L., Overgaag M. (2022): European Hydrogen Backbone | Supported by Guidehouse | 2022 → https://ehb.eu/files/downloads/ehb-report-220428-17h00-interactive-1.pdf

[30] Wang B. et al. (2018): Energy consumption analysis of different BEV powertrain topologies by design optimization | 2018 → https://link.springer.com/article/10.1007/s12239-018-0087-z

[31] Weiss M., Cloos K., Helmers E. (2020): Energy efficiency trade-offs in small to large electric vehicles | Env. Sciences Europe | 2020 → https://enveurope.springeropen.com/articles/10.1186/s12302-020-00307-8

[32] World Road Association (2018): Electric Road Systems: A solution for the future? | 2018 → https://www.piarc.org/en/order-library/29690-en-Electric%20road%20systems:%20a%20solution%20for%20the%20future

[33] https://www.asfinag.at/bauen-erhalten/bauprojekte/ | 15.11.2022

[34] https://www.austriatech.at/de/leitstelle-elektromobilitaet/ | 31.03.2023

[35] https://www.auto-motor-und-sport.de/tech-zukunft/alternative-antriebe/wasserstoff-brennstoffzellen-lkw-500-km-reichweite/ | 10.11.2022

[36] https://www.autobild.de/artikel/man-e-bus-elektro-test-nachhaltigkeit-reichweite-preis-21448921.html | 10.11.2022

[37] https://www.bmk.gv.at/themen/verkehr/strasse/publikationen/statistik_strasseverkehr.html → 15.11.2022

[38] https://www.bosch.com/de/stories/wasserstoff-lkw/ | 10.11.2022

[39] European Commission | Climate Action | 2050 long-term strategy → https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy_en#:~:text=The%20EU%20aims%20to%20be,AgreementEN%E2%80%A2%E2%80%A2%E2%80%A2 | 10.11.2022

[40] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_de | 06.03.2023

[41] https://www.consilium.europa.eu/en/infographics/fit-for-55-afir-alternative-fuels-infrastructure-regulation/#:~:text=The%20alternative%20fuels%20infrastructure%20regulation,Commission's%20proposal%20for%20this%20regulation | 17.04.2023

[42] https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/ | 17.04.2023

[43] https://www2.deloitte.com/at/de/seiten/strategy-analytics/articles/h2-mobility-austria.html | 04.11.2022

[44] https://www.designwerk.com/elektrische-lastkraftwagen/ | 10.11.2022

[45] https://www.eea.europa.eu/ims/new-registrations-of-electric-vehicles | 15.03.2023

[46] https://efahrer.chip.de/e-wissen/e-lastwagen-2021-hersteller-modelle-von-elektro-lkw_10378 | 10.11.2022

[47] https://elways.se/ | 04.11.2022

[48] https://www.enbw.com/blog/elektromobilitaet/fahren/elektro-transporter-aktuelle-modelle-im-ueberblick/ | 10.11.2022

[49] https://energy.ec.europa.eu/publications/delegated-regulation-union-methodology-rfnbos_en | 17.04.2023

[50] https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en | 17.04.2023

[51] https://www.ffg.at/ENIN | 31.03.2023

[52] https://flaechentool.de/ | 10.11.2022

[53] https://hydrogeneurope.eu/h2-talks/eu-projects/ | 27.02.2023

[54] https://hyundai-hm.com/unser-truck/ | 10.11.2022

[55] https://infoportal.mobil.nrw/technik/busse-mit-elektrischem-antrieb/brennstoffzellen-linienbus.html | 10.11.2022

[56] https://www.ladestellen.at/ | 18.03.2023

[57] https://www.land-oberoesterreich.gv.at/Mediendateien/Formulare/Dokumente%20UWD%20Abt_US/4_RK_18_Gutachten_OoeLaHol_FINAL_20181221.pdf | 20.03.2023

[58] https://markt.apg.at/netz/netzverluste | 04.11.2022

[59] https://media.daimlertruck.com/marsMediaSite/de/instance/ko/GenH2-Truck.xhtml?oid=47469461 | 10.11.2022

[60] https://nederlandelektrisch.nl/Charging-infrastructure | 18.3.2023

[61] https://nederlandelektrisch.nl/e-rijden-in-mijn-gemeente/kennisloket-gemeenten | 18.03.2023

[62] https://nederlandelektrisch.nl/actueel/nieuwsoverzicht/i435/provincie-noord-brabant-en-limburg-organiseren-aanbesteding-voor-2-500-slimme-laadpunten | 18.03.2023

[63] https://www.omv.com/services/downloads/00/omv.com/1522167901007/dload_Factsheet_hydrogen_Mobility_EN | 04.11.2022

[64] https://www.umweltbundesamt.at/mobilitaet/technologie/synthetische-verbrennungskraftstoffe | 23.02.2023

[65] UNFCCC | United Nations Framework Convention on Climate Change → https://unfccc.int/ | 10.11.2022

[66] https://www.vanhool.com/de/fahrzeuge/reisebusse/reisebusse-usa/cx45e | 10.11.2022

[67] www.verkehrsmodell.at | 10.11.2022

[68] wien.orf.at: Weiter Gezerre um Tarife für E-Tankstellen
→ https://wien.orf.at/stories/3197178/ | 08.03.2023

[69] https://www.wienerlinien.at/f%C3%BCr-noch-mehr-klimaschutz-wir-testen-wasserstoff-bus-von-hyundai | 04.11.2022

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APPENDIX

- Workshop protocols
- GREENROAD projection model | Config file showing relevant input parameters