Sustainable passenger transport: Policy development under an integrative transport system, economic and legal perspective

Karl Steininger, Raphaela Maier, Christoph Romirer, Georg Jäger, Simon Plakolb, Annina Thaller, Stefan Nabernegg, Alfred Posch, Eva Schulev-Steindl, Eva Fleiss, Holger Heinfellner, Oswald Thaller

For discussion at stakeholder dialogue - September 2021

Abstract

Greenhouse gas emission mitigation has emerged as a crucial challenge for the passenger transport system, adding to other environmental, health and transport system (congestion) challenges. In addressing both multiple challenges and in a socially acceptable and politically feasible way, sets of diverse instruments composing policy packages are sought. In this contribution a framework to identify such a package is explored, applied to identify one for the EU member State of Austria, and this policy package is evaluated. To achieve a zero-emission passenger transport system by 2040, an admission ban for fossil-fuelled cars appears necessary of as early as 2025, and legally possible at the EU level. A set of further pull and push measures is identified, as this shift to e-mobility alone falls short of solving the full range of challenges. Timely redirection of infrastructure development and education are crucial to keep economic transition costs low. Overall, a thus transformed transport system exerts lower total social costs on the society, granting a further incentive for its implementation.

Keywords: climate-neutral transport; climate policy; transport policy package; policy impact analysis

1. Introduction

Operation, development and future system design of passenger transport and respective policies have to address multiple challenges (e.g., van Wee et al., 2013; Francis and Hurdle, 2020). During the last decades climate change emerged as an additional concern, with the transition to a climate neutral transport system meanwhile forming a political target worldwide (OECD/ITF, 2007; UNFCCC, 2015; IPCC, 2018). Reducing greenhouse gas emissions to net-zero has to be accomplished while simultaneously also addressing the other challenges and concerns (Holden et al., 2020). The multidimensional policy targets imply the integration of multiple policy instruments into a package (Thaller et al, 2021). In this contribution we explore fundamental aspects to be considered in the design of such a package, a practical process to identify its elements, and discuss its evaluation at a national scale.

Passenger transport in its current form is associated with a range of challenges, in particular noise, local air pollution, geographical sprawl, affordability, safety and health issues (Jochem et al., 2016; Santos et al., 2010; Steg and Gifford, 2005). By means of the UN Paris Agreement the global community declared its concern also on climate change and is seeking to limit global warming to below 2 degrees (relative to pre-industrial), with efforts to remain below 1.5 degrees. The latter requires global net carbon neutrality around mid of the present century (to achieve this target with a likelihood of 2/3 by 2040, with one of 50% by 2055; IPCC, 2018), the former during its second half.

In its Special Report on the 1.5°C climate target, the IPCC identified the substantial effort this implies: "Pathways limiting global warming to 1.5°C with no or limited overshoot would require rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems (high confidence). These systems transitions are unprecedented in terms of scale, but not necessarily in terms of speed […]." (IPCC, 2018, p. 15 (C.2))

To achieve such a transition in passenger transport, a substantial societal effort is required. In the analysis supporting the development of according policies literature to date has mainly focused on the evaluation of single policy measures, with road pricing (Kalinowska & Steininger, 2009; Mayeres, 2000; Steininger et al., 2007), fuel taxes (Mayeres, 2000; Sterner, 2007), fuel standards (Karplus et al., 2015; Karplus & Paltsev, 2012; Paltsev et al., 2018), subsidies for public transport (Mayeres, 2000; Tscharaktschiew & Hirte, 2012) and speed limits (Nitzsche & Tscharaktschiew, 2013) among the policies investigated. More recently, an increasing number of researchers is calling for balanced policy packages to address the multiple challenges policymakers are facing (Axsen et al., 2020; Givoni, 2014), as the approach we follow . Nonetheless, studies investigating the effects of policy packages and the interactions between the instruments included are still scarce (Bhardwaj et al., 2020). Examples include Lam & Mercure (2021), Fox et al. (2017) and Small (2012).

Similarly, in the evaluation of either single policies or policy packages, the literature to date focuses mainly on single perspectives, including the transport system (e.g., Lee (2018), Hofer et al. (2018), Morton et al. (2017)), economic prerequisites and implications (e.g., Sterner 2012, Pizer and Sexton 2019, Acemoglu et al. 2012) and legal aspects (e.g., Held et al. (2021), Geringer/Romirer (2020), Högelsberger (2019), Kerschner (2016)).

An important finding regarding the possible effects of a policy on the traffic system is that rebound effects can occur. Lee (2018) finds that while an increase in road capacity can optimize traffic flow, the positive impact on emission reduction is outweighed by the additional traffic induced by such an expansion. This is in line with the findings of Hofer et al. (2018), who show that expanding the road network is unsuitable to decrease emissions and that a combination of policies (e-mobility, offering alternatives to private car use, and avoidance of trips) has the largest potential to decrease emissions. Policies can also affect another part of the traffic system, namely the fleet composition. Morton et al. (2017) find that the exemption of a charge, in this case the London Congestion Charge, which needs to be paid when driving inside London, significantly increased the number of registrations for Hybrid Electric Vehicles, thereby leading to less emissions. However, since all policies of a policy package interact in a non-trivial way, it is difficult to estimate their combined effect based on individual studies and a more holistic analysis is required.

From an economic perspective, a carbon or fuel pricing policy is considered as most effective way to reduce economy-wide transport emissions. The main argument against a fuel tax policy are equity concerns, that claim that the poor are stronger burdened by such policies than the wealthy. However, e.g., Sterner (2012) shows, that even without revenue use from a tax, the distribution of policy burden of a fuel taxes depends on various aspects of the specific country and transport system. Even with a larger direct burden on the poor, progressive redistribution of tax revenues potentially outweighs this negative effect (Pizer and Sexton 2019). Furthermore, Acemoglu et al (2012) emphasize the importance of a combination of tax instruments with research subsidies in an optimal policy mix. They show that in an endogenous growth model with environmental constraints, that a carbon tax can be lower if combined with subsidizing investments in the development and deployment of new green technologies, which results in an intertemporal welfare maximization.

Applied transport policy analysis requires to choose a specific context. We here choose the national scale of Austria as an exemplifying case to derive and check our approach and results, while identifying those that can be generalized in the discussion. While globally the transport sector accounts for 23% of global greenhouse gas (GHG) emissions (IPCC, 2018), in the industrialized country Austria the share is even higher, amounting to 30% (Anderl et al., 2021). In many countries world-wide this share is actually still increasing, often fostered by other sectors having started to effectively reduce transport emissions, or do so at least faster. In Austria transport GHG emissions have risen even in absolute terms, more or less consistently since the base year most climate agreements refer to, 1990. Their share thereby has increased from 17.5% (1990) to 30% (2019). Acknowledging just the measures implemented, growth and at some point also the absolute level is predicted to decline (ref to UBA WEM scenario), tremendously failing Austrian climate targets. The recent EU Commission climate package proposal has Austria to decline non-Emission Trading System sectors (which transport is part of) by 48% by 2030 (relative to 2005, European Commission, 2021), according to the government agreement Austria seeks to achieve climate neutrality by 2040. Consequently, substantial additional effort is required. This choice of context, Austria, also defines the legal background of a Member State of the European Union.

From a legal perspective, policy packages can include "regulatory" measures that are relatively intervention-intensive and directly affect behavior. For example, bans on the use and registration of fossil-fueled cars. As an alternative or in addition, "economic" measures can be taken that indirectly influence behavior through financial incentives and, like eco-taxes or carbon pricing, make climate-damaging actions more expensive and internalize external costs. Concerning the legal feasibility of such measures, the Austrian legislator operates in a multi-level system: In addition to the requirements of national law, e.g. the constitutional division of competences and the fundamental rights, he has to observe EU law, in particular the fundamental freedoms, the Charta of Fundamental Rights as well as the relevant secondary legislation. Hence, if de lege lata (as the law stands) there is no leeway under EU law for certain measures, their implementation requires much greater (political) efforts compared to merely amending simple laws or even issuing an ordinance.

Against this background, bans on the registration or use of fossil-fueled cars, for example, may be compatible with national law, but, as things stand at present, are in conflict with EU law (Held et al., 2021). Member states therefore are currently unable to introduce such bans on their own. From a domestic perspective, their admissibility particularly depends on whether they are suitable and necessary to achieve the objective or if there are less restrictive means, such as environmental taxes or various forms of carbon-pricing (Högelsberger, 2019, Kirchengast et al. 2020). The legal legitimacy of a measure can therefore often only be assessed in connection with other measures: If, for example, an economic or empirical assessment shows that greening the tax system (e.g. because of insufficient incentives) is not enough on its own to achieve the goal of climate neutrality, this justifies additional, more drastic measures, such as bans on the use and registration of fossil-fueled cars. Thus, legal reasons may make it advisable too to consider policies in form of packages instead of individual isolated measures.

The policy package developed in the following has to meet three demands, each of which we evaluate this package for in the discussion. Beyond carbon neutrality by 2040 to be first achieved in a technologically feasible way in the passenger transport system, the timing, second, also has to be feasible within the legal framework. Finally, Political acceptability evidently is crucial for constituting a feasible package.

The remainder of this paper is organized as follows. Section 2 develops the composition of the policy package, and section 3 its timing. Section 4 identifies the agents to act, before section 5 discusses and evaluation of the package against the criteria of technological and legal feasibility, economic implications and public acceptance. A final section concludes.

2. Policy packages: designing the composition

2.1. Changes beyond technological progress

A fundamental question in the design of sustainable passenger transport policy packages is their composition, i.e., what type of measures should be included. There exists a wide range of potential policy measures and relevant objectives. However, it is less clear how to integrate them into a successful package. Some argue that such policy packages aiming at behaviour change are unnecessary because the shift to electromobility will solve the passenger transportation climate problem on its own. However, not only the production of such a large quantity of electric cars would be a challenge, but also the use phase, in particular given the ever-increasing demand for mobility. Existing congestion problems, especially in urban areas, could continue to worsen. Consequently, non-carbon emissions such as tire wear and road noise would also increase. Thus, shifting to e-mobility alone is not sufficient and one needs to also aim at reducing car usage in general. In order to illustrate the effect of the composition of a policy package on car usage, **Fehler! Verweisquelle konnte nicht gefunden werden.** shows a comparison of four congestion maps of the City of Vienna obtained by using the traffic model Tranciton (Plakolb et al. 2021) for different policy scenarios.

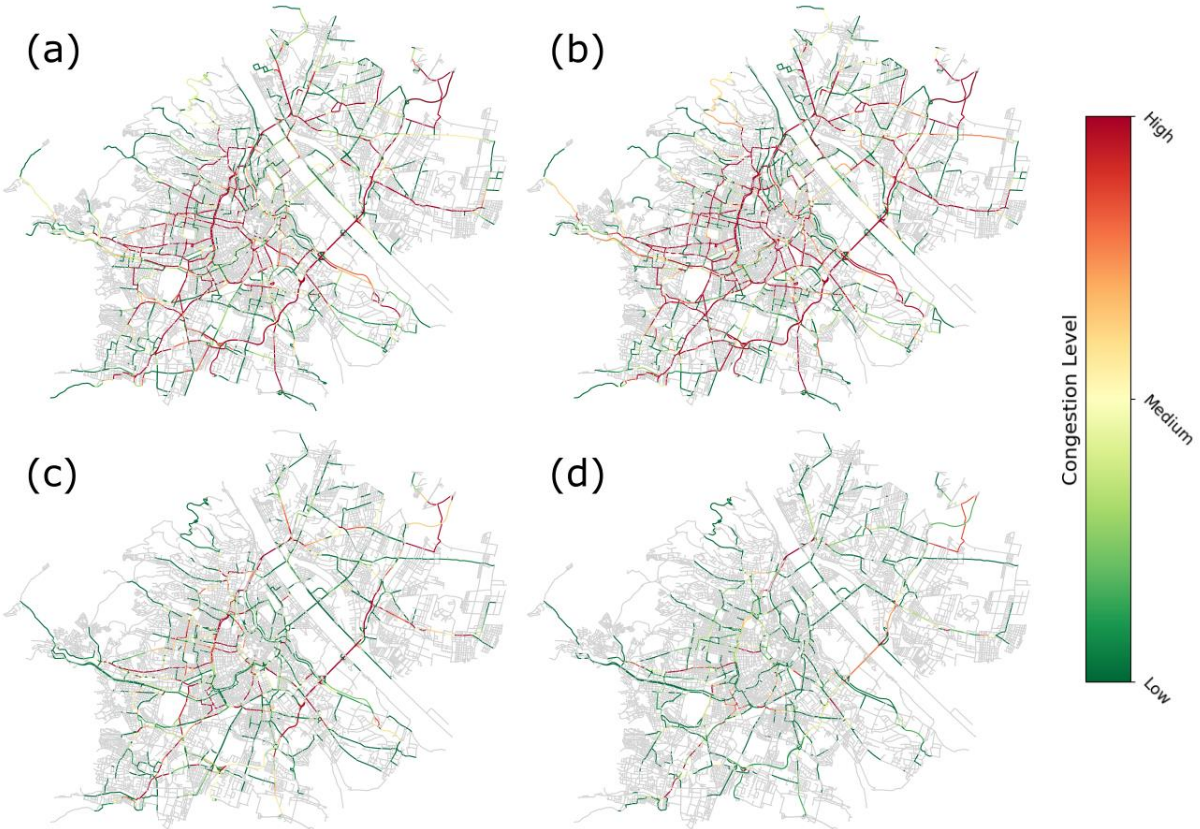

Figure 1 Congestion maps that show the effects of different policy packages: (a) current situation, (b) effect of a policy package that focuses on e-mobility, (c and d) balanced policy package including shift effects of 50 % of traffic (c) and 66 % of traffic (d).

Panel shows the situation in 2020: Red roads are heavily congested, while the traffic on grey road segments flows freely. The scenario analysed in the panel (b) shows the traffic system in 2040 with a policy package that focusses solely on e-mobility. It is clearly visible that the traffic situation does not improve and, in many cases, even worsens. A balances policy package including shift effects of 50 % of MIV mitigates these effects as shown in panel (c). Finally, the panel (d) depicts the effects of an ambitious policy package shifting two thirds of MIV to other transportation modes. For example, some 50 % of MIV traffic could be shifted to public transport while the remainder could result in active mobility. Here, the traffic situation improves drastically, which does not only alleviate the secondary negative effects of road traffic, but also means that significantly less electricity is needed.

This is essential, since providing enough electricity for a fleet consisting solely of electric cars is challenging, especially considering that only renewable energy sources should be used. Even assuming the car usage of 2015 (which is significantly lower than what we expect for 2040), the resulting demand for electrical energy would be about 20% of the current electricity consumption of Austria. Meeting this demand is particularly difficult, as it can lead to a rapid and sharp increase in energy consumption during peak periods.

Considering these aspects, we see the need for further policy measures that go beyond technological solutions. Therefore, we here focus on the composition of the package of measures by examining (i) which policy measures might be relevant and (ii) what trade-offs and synergies might exist between them.

2.2. Designing disruptive policy packages

To tackle the emission reduction challenge of passenger transport it is necessary to develop policy packages that strike the balance between disruptiveness and implementability, therefore combining effective push measures (e.g., car bans or price increases) with additional pull measures and incentives (e.g., better public transport connections) (see Thaller et al., 2021, Figure 5). There exist multiple ways to design a specific package, however, changes in infrastructure and spatial planning will be inevitable to enable the necessary changes. While in the past the focus was often solely on improve policies, shifting to alternative modes and avoiding traffic where possible are additional critical cornerstones for a successful policy package (Thaller et al., 2021). Based on these findings, we differentiate between three main policy packages according to the type of push measures included. In addition, all packages included a set of pull measures that address relevant topics that need to be considered (see Table 1).

Table 1: Disruptive policy packages

Regulatory package (P1)	Capacity package (P2)	Economic package (P3)
[1] Ban on new/first registration of cars with internal combustion engines	[4] Restriction on the overall admission and operation of fossil fueled cars	[7] Enhanced ecological taxation
[2] Ban on the use of cars with internal combustion engines	[5] Car-free city centers	[8] Introduction of a city toll
[3] Management and reduction of parking areas	[6] Reduction and redesign of street space	
All packages (P1-P3)		
[9] Basic ecological taxation	[14] Reduction of speed limits	[19] Raising awareness for alternative mobility modes
[10] Road Pricing	[15] User-oriented public transport kick and guarantee	[20] Intelligent technologies and digitalization
[11] Socio-ecological redesign of commuting allowance system	[16] Carpooling/-sharing, on-call bus and share taxis	[21] Teleworking
[12] Electrification of individual motorized transport: Financial incentives and infrastructure	[17] Support of non-motorized private transport	[22] Company mobility Plans
[13] Electrification of public transport	[18] Regional development and planning	[23] Mobility efficiency act

Although our findings clearly show that a combination of push and pull measures is necessary to address climate challenges in passenger transport, fear of low public acceptance has led to policy inertia in this area. However, we find that presenting push measures as part of a comprehensive package of measures, which includes both incentivizing and restrictive measures, leads to higher acceptance of such restrictive measures than when presented in isolation (Thaller et al., 2021b, Figure 3).

While the primary target of each of the three policy packages is to effectively reduce GHG emissions, their instruments also address further transport challenges, such as constraints of resource availability (e.g., renewable electricity), local air pollution and health effects. To shed light on the range of policy effects, we qualitatively structure each measure of the policy packages according to an avoid-shift-improve policy concept (Banister, 2008, Creutzig et al. 2018) and link the latter to a set of impacts (see Figure 2).

Figure 2 indicates for each instrument which of the three policy classes (avoid – shift – improve) it fosters most (a stronger impact signalled by stronger line thickness). Each of these policy classes is then linked to positive (blue) or negative (red) effects on different target dimensions. The set of targets are based on evaluations of external costs of transport (van Essel et al. 2019, Gössling et al. 2019), economic (distributional and innovation) and public acceptance considerations.

Strongest contributions to avoid policies are measures that treat mobility as a mean to achieve access for people in societal activities [18,21] or aim at limiting underutilized infrastructure [16, 22]. Most measures from the policy package also show a shift component. Those either restrict car use by legal [4,5] or economic means [7,8,10,11] or support alternatives transport modes [15,17]. Improve measures, on the other hand specifically targeting a switch to ZEVs by legal means [1,2,4] or the electrification of the transport system [12,13].

While reductions of GHG emissions as well as air quality, noise and direct travel costs are addressed through all three mechanisms, avoid and shift measures target also congestion and safety aspects. Health benefits are strongly impacted by shifts to active mobility. At the same time, shift measures bear increases in travel time and rather low public acceptance. Economic targets of distributional effects and innovation are rather positively affected by shift measures, while improve measures bear potentially negative distributional effects.

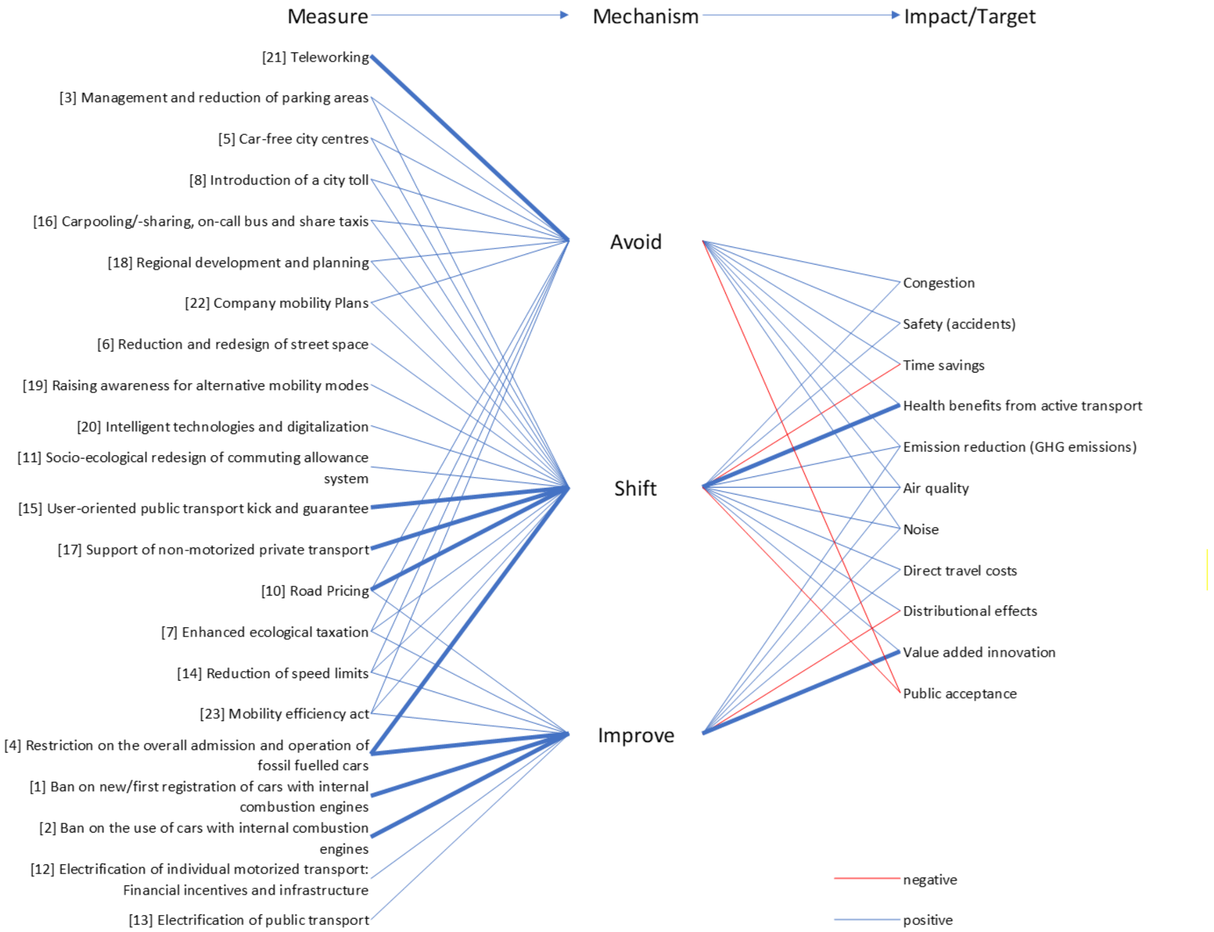

Figure 2 Overview of instruments and their impact transmission on different target dimensions

3. Policy package: designing the timing

3.1 The legal sustainability trade-off

For the transport sector to contribute to the goal of climate neutrality and ultimately become climate neutral itself, disruptive measures are needed urgently. However, disruptiveness potentially stands in conflict with the Austrian constitution, which protects legitimate expectations ("Vertrauensschutz"). For example, when acquiring a new car today, one typically is expecting being allowed to use it for many years to come. Based on the operating licence and the underlying law, but particularly on the constitutionally guaranteed fundamental right to property, the car owner has a "rights-based expectation" (Meyer et al., 2021).

The principle of legitimate expectations does not, however, entirely or necessarily prevent the state from introducing legislative amendments that disappoint those expectations: Rather, the legislator's objectives have to be balanced against them. The former can outweigh the latter if the interference in well-acquired rights is proportionate – representing another, universal (Beatty, 2004) constitutional requirement. Against this backdrop, the law amendment frustrating one's legitimate expectations must be of public interest, impose a suitable means to meet this interest, be the least restrictive means to obtain its objective, and be proportionate in the narrow sense. The balancing process to be carried out in the last step leads to a value judgement which is, to a certain degree, of subjective nature (in that sense Uerpmann, 2001). An important aspect for proportionality is the time horizon of implementation: Usually, the legislator provides for transition periods.

Yet this does not mean that a short-term introduction of a disruptive policy aiming to change the transport system is necessarily disproportional and unconstitutional. If there is an urgent need, a short-term change in the legal situation is very much possible in the short term. Moreover, the mere trust in the unchanged continuation of the applicable legal situation as such (i.e. with no underlying right) does not enjoy any special constitutional protection, which must also hold for the transport sector. For example, a registration ban on fossil fuel cars does not frustrate the expectations of potential customers to purchase a particular car in the same way as an operating ban where the car has already been purchased and is owned by someone.

3.2 The technology and mobility system trade-off

For the possibility of completely decarbonised passenger transport, every passenger car needs to be powered by an electric motor by 2040. Since the life time of a car in Austria is roughly 15 years, this means that after 2025, all newly admitted cars need to be electric. The required speed of such a transition is visualized in Figure 3, which shows the amount of electric cars as a percentage of all new registrations. Values up to the year 2021 are taken from UBA (2021). The red curve is an extrapolation of the current path, assuming that the rise in the share of admissions of electric cars at 5%-points per year continues. The yellow curve assumes a more optimistic scenario, in which the increase of electric cars is double the rate observed in the last years. It is clearly visible that both paths fall short of the target of 100% in admissions in 2025. What is needed is an exponential path, shown in the green curve, calculated from an exponential fit with the boundary condition, that 100% of all newly registered cars in 2025 need to be powered by an electric motor.

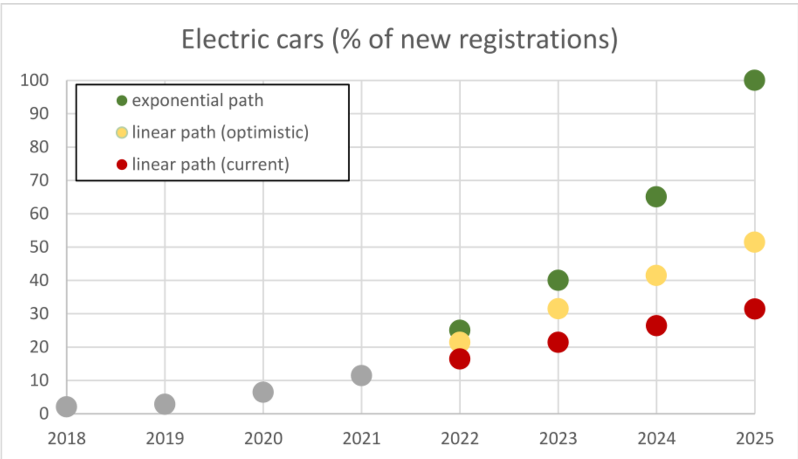

Figure 3 Amount of electric cars as a percentage of all new registrations in Austria: Statistical values (gray), linear path (red), optimistic linear path (yellow), exponential path (green)

It is clear that the required transition is exceptionally steep. However, there are many technological constraints that limit how fast such a transition can happen.

The production of electric cars faces a significant bottleneck: Batteries require lithium, and the supply of lithium is constrained, not only in quantity, but also in quality (Narins, 2017). Additionally, the need for cobalt presents a challenge, not only because cobalt is a conflict mineral (Sovacool, 2019).

Furthermore, the required infrastructure for charging a large number of electric vehicles is not yet present. This includes not only the charging stations themselves, but also a suitable power grid as well as power plants that ensure that the additionally required electricity can be produced from CO_2-neutral sources.

Thus, from the technology perspective, the diffusion of electric cars and the related exnovation of cars using a combustion engine leads to the greatest restrictions in the timing of the policies. This transition needs to start as soon as possible, since the first milestone, i.e. 100% of all newly registered cars to be electric, should already be achieved by 2025.

3.3 Legal constraints

As with all measures focusing on climate neutrality in the transport sector by 2040, the main legal question that arises when transitioning to electric cars by a certain time is its conformity with EU and constitutional law. If all newly registered cars are to be electric only from 2025 onwards, a legally binding ban on the registration of passenger cars with combustion engines would have to apply from that time onwards. Accordingly, some EU member states have already announced their intention to enact such bans. Moreover, while presenting its recent “Fit for 55”-package, the European Commission set the target of new vehicles emitting “zero CO_2” by 2035 (European Commission, 2021), which could - de lege ferenda (law to be proposed)- amount to an EU-wide ban on the admission of new petrol and diesel cars from that date.

However, an admission ban would particularly have to meet the requirements of EU secondary law. First and foremost, Regulation 2018/858/EU lays down "harmonised rules and principles for the type-approval of motor vehicles" and explicitly obliges the member states to register and operate all vehicles covered by it: Among other things, they shall not restrict or impede the placing on the market, registration or entry into service of vehicles that comply with this Regulation. A national admission ban of passenger cars with internal combustion engines would therefore not be compatible with current EU law. The same result holds when considering a possible exception clause in the Treaty on the Functioning of the European Union, which would enable national action in the case of a “specific” environmental problem. Most certainly, the Commission would not accept climate change as such, even though it must be clear that a state cannot evade its responsibility by invoking the international character of climate protection. Other than that, Under EU primary law, such a *de facto* usage restriction would impose an obstacle to sales and thus interfere with the free movement of goods. However, according to the case law of the European Court of Justice, an encroachment could possibly be justified on the basis of overriding reasons in the “public interest" (ECJ *Cassis de Dijon*), which also includes environmental protection (ECJ *Commission/Denmark*).

Concerning usage bans – which would have to be implemented by 2040 at the latest – another potential legal obstacle opens up, as such a ban represents a considerable interference with the fundamental right to property. Its proportionality and legal conformity particularly depends on the absence of less restrictive, equal measures (e.g. the effectiveness of carbon pricing) which - in view of the urgency of the climate crisis - is probably justifiable given a longer lead time and the increasing availability of alternative driving technologies as well as corresponding infrastructure.

Last but not least, the probably most important legal issue concerning an admission ban from 2025 onwards is the constitutionally guaranteed protection of legitimate expectations, derived from the principle of equality (Art 7 B-VG) and already discussed in 3.1. Accordingly, the mere trust in the unchanged continuation of the applicable legal situation as such does not enjoy any special constitutional protection, which must also hold for the transport sector (Hiesel, 2017). However, restrictions of well acquired rights are unconstitutional if they represent serious and sudden interventions in legal positions on whose existence those concerned could have had good reason to trust.

3.4 Economic considerations

Economic considerations on the timing of policy measures in climate policy packages in general and for a transition in the transport system in particular are focusing on three different aspects of providing framework conditions. Framework conditions concern the availability of competitive climate friendly technologies, the availability of infrastructure by timely investment, and, finally, implications for the size of ultimately stranded assets, in particular with respect to the vehicle stock.

The consideration of innovation and technological change suggests that the earlier and stronger measures are taken to direct technology development towards a transition to a climate neutral economy, the lower will be the aggregated economic costs over time. Furthermore, when measures are sufficiently strong to direct the economy on a sustainable growth path, measures can be only temporary (Acemoglu et al. 2012). Furthermore, deploying an international first mover advantage in alternative transport technologies may generate export opportunities to international markets.

Additionally, infrastructure conditions are necessary providing e.g. sufficient networks of charging stations for electric vehicles or public transport to allow a switch to these alternatives. Build-up of such infrastructures needs to be started in due time. Conversely, current extensive road investments and their lengthy construction times may imply them representing stranded assets upon completion, when a stronger transition to public transport and active mobility will have occurred rendering them underutilize.

A similar economic cost argument can refer to the vehicle stock, based on the aspects of vehicle use time and vehicle stock composition. If policies lead to a phase-out of fossil fuelled cars before their end-of-life it would imply stranded assets of not utilizing vehicle investment. While on a global level over-committed emissions from a business-as-usual investment are largest in the power sector, also in passenger transport such relevant stranded assets can occur (especially for shorter time policy targets for 2030 or 2040) (Erickson et al. 2015). Considering the technology market share of fossil-fuelled cars, techno-institutional lock-ins are even estimated highest for passenger transport, compared to all other areas of power, industry or buildings (Erickson et al. 2015, Seto et al. 2016). For Austria a particular challenge presents the relatively young vehicle stock (ACEA, 2021), when considering average use times of 15 years. From a firm perspective, the legal allowance for depreciation of passenger vehicles however is only 8 years, locating costs of a fast transition rather to private car owners. The practical use time of private passenger cars however depends on admission requirements, maintenance and operation costs as well as on driver preferences. Influencing these legal and economic aspects as well as shaping preferences and providing alternatives presents the core of a policy package. The precise timing of legal measures or paths for economic (tax) measures is essential to minimize the stranded assets in such a transition.

4. Policy package: agency - interacting levels of regulation

4.1 Climate neutrality 2040 and call for action in the transport sector – Legal background

The European Union is pursuing a relatively ambitious climate policy against the backdrop of the Paris Agreement. In 2019, for example, the Commission set the ambitious goal of reducing greenhouse gas emissions in the EU by 55% until 2030 with the "European Green Deal" in order to achieve "climate neutrality" by 2050 (see COM/2019/640 final). In the first half of 2021, the Council and Parliament then agreed on a corresponding EU climate law (2020/0036 (COD) and the Commission called for adapting

EU climate, energy and transport legislation towards climate neutrality in its "Fit for 55" package (see COM/2021/550 final).

Based on the „Effort-Sharing Regulation" 2018/842/EU, in 2030, Austria has to reduce its (non-ETS) GHG emissions at least by 36% in relation to 2005. The regulation leaves it up to the member states to decide on the measures they will adopt to achieve their emission reduction targets. With the climate law package of July 2021 all national Member State targets are to increase their ambition, currently under negotiation (the proposal of the European Commission suggests a 48% emission reduction for Austria by 2040). Regulation 2019/631/EU sets so-called fleet-wide targets with regard to CO_2 emissions, according to which newly registered vehicles may not exceed a certain emission limit value. From 1.1.2025, this value shall be reduced by 15% based on the fleet-wide targets for passenger cars and light-duty vehicles, and from 1.1.2030 by 37.5% and 31% respectively. Regulation 2019/1242/EU sets fleet-wide targets for heavy-duty vehicles. According to it, CO_2-emissions shall be reduced by 15% from 2025 onwards, and by 30% from 2030 onwards compared to the regulation's reference CO_2-emissions. The „Clean Vehicle" Directive 2019/1161/EU particularly applies to the procurement of road transport vehicles by contracting authorities or entities. For light-duty (car or van) vehicles, it contains tail-pipe and real driving emission limits, whereas heavy-duty (truck or bus) vehicles must, in general, use alternative fuels. The directive commits the member states to minimum procurement targets of these "clean" vehicles in two reference periods.

4.2 Policy packages – Interacting levels of regulation

The different instruments of the policy package, and often even single instruments of them, address different legal layers. We thus focus here on the interacting levels of regulation between the EU and Austria as well as the different layers of Austrian national law. Every policy has to correspond to the **legal system's hierarchy**: First and foremost, the fundamental principles ("Baugesetze") of the Austrian constitution must be respected. This implies interpreting all federal and *Laender* laws in the light of these principles (Öhlinger/Eberhard, 2020). Next, possible EU law boundaries such as the internal market, fundamental freedoms and the fundamental rights have to be considered and may – in case of a conflict – override constitutional law other than the fundamental principles. Apart from this, the national legislator always has to observe constitutional requirements and, in turn, defines the scope for administrative action, also including lawmaking by means of ordinances.

Austria being a **federal state**, the federal states ("Laender") have, besides the federation ("Bund"), also **independent legislative competences** - thus there are ten different legislators. Municipalities, however, do not have any legislative competence, they can issue only ordinances. As far as the powers to regulate transport or mobility-related measures are concerned, these are largely with the federation, but the Laender also have important responsibilities. In exercising their legislative powers, the federation and the Laender must each respect the interests of the other authority and not undermine them with their regulations ("Torpedierungsverbot").

In addition to the hierarchy of norms and the distribution of competences, the question of **proportionality** is a central criterion that must be observed when implementing the various policies. This requirement arises both from EU law (e.g. the Charter of Fundamental Rights and the fundamental freedoms) as well as from the national constitution's fundamental rights. It means that every policy has to be of public interest, suitable and necessary to obtain its objectives and be proportional in the narrower sense (Barak, 2012).

Considering our policy packages, the last two requirements are of particular importance: "Necessary" means that the authority must choose the least restrictive means to achieve the objective perceived, interfering in fundamental rights as little as possible. This also is a question of alternatives: Regulatory policies like, for instance, a usage ban on fossil-fueled passenger cars, aimed at reducing GHG emissions, severely interfere in one’s fundamental right to property. If a less restrictive policy, such as CO_2-taxation, which only creates a financial incentive to switch to climate-friendlier means of transportation, can achieve the same goal, a usage ban would be unproportional, hence unconstitutional. “Proportional in the narrower sense” implies that a policy to be legal requires opposing interests to be balanced: Is the individual’s right to freely drive in inner cities worth more than climate protection pursued with the implementation of an environmental zone, or vice versa? The legal system must therefore be considered as a whole: One measure always impacts other areas.

To showcase these interacting levels of regulations and legal principles, in the next step, exemplary policies are taken out of their packages, outlining the main legal opportunities and challenges.

4.2.1 EU law – Federal law

Prime examples for policies directly dependent on EU-law requirements would be **admission and usage bans of fossil-fueled passenger cars**: As already shown in 3.3, these policies would require an amendment of EU secondary law in order to be introduced in Austria. To actually do so, these bans would probably have to be implemented into the Motor Vehicle Act, which i.a. regulates the admission of passenger cars, as well as into the Road Traffic Act, which provides rules for road users.

Another important measure would be the introduction of the so-called “**CO_2 -pricing**”, which internalises the external costs of climate change and charge them to emitters - in line with the polluter pays principle.

An Austrian **CO_2 tax** would, in turn, have to fit into the EU legal framework: For example, the Energy Tax Directive, implemented in Austria through the Mineral Oil Tax Act, provides for minimum tax amounts for various mineral oils. However, these do not reflect the CO_2 intensity of the respective energy products. A genuine carbon tax could be based on emissions caused (“emission approach”), on the fuel as such ("fuel-based approach") or directly on a product ("consumption-based approach ") (Damberger, 2021). A variant of the latter approach is the "carbon added tax" (CAT), similar to the value-added tax, although not linked to the value of the goods, but to the CO2 emissions generated during production.

As to the question of competences: Generally, the federation has the so-called "competence competence". This means that the federal legislator distributes the taxation rights between the authorities and could therefore levy a CO2 tax itself or empower the Laender to do so. The latter, in turn, could also levy a CO2 tax independently of such an authorization on the basis of their "right to invent levies", but should not counteract existing federal taxes in doing so.

Furthermore, a CO2 tax must comply with the constitutional requirement of objectivity under the principle of equality. This is of particular importance if the introduction of the CO2 tax places an additional burden on goods already subject to taxation, e.g. energy taxes. Thus, there is an increased pressure to justify the CO2 tax. (Damberger, 2021). Moreover, the tax must not result in an unconstitutional **"stranglehold tax"** forcing taxpayers to stop "undesirable" behavior altogether as a result of the burden (Ruppe, 1982).

Closely linked to CO2-pricing is the concept of **road pricing**. The Austrian „Vignette“ system which enables using Austrian motorways according to the Federal Road Toll Act is of time-dependent nature and doesn’t take the extent to which a road user causes CO_2 emissions into account. Thus, it does not reveal the "true" costs of transport. This creates an incentive for more usage, because those who do not use motorways on a regular basis significantly pay more per kilometre. In contrast, a "road pricing" system, according to which all costs associated with the use of the car are no longer only or primarily time-dependent, but in particular mileage-dependent, would ensure true-cost pricing. Under current EU law, member States are bound by primary law only with regard to vehicles under 3,5 t. For heavier vehicles directive 1999/62/EC applies. Currently, an amendment to this directive is pending, in which external costs and thus environmental and climate pollution are to be considered stronger. In particular, cars, buses and light commercial vehicles will also be covered by the system from 2028 on, and it will no longer be differentiated according to EURO emission classes.

4.2.2 Federal law

A possible redesign of the **commuter allowance** is solely a matter of federal law. Neither the "small" nor the "large" commuter allowance offer a special incentive to use a climate-friendly means of transport yet. It would therefore be conceivable to entirely remove the small commuter allowance, which is granted even though public transport would be “bearable”, or at least to introduce **ecological criteria** into the relevant provision. For example, only those who commute by public transport could be granted the maximum allowance, all others only a part of it. When introducing this measure, one has to pay attention to the socially vulnerable again and possibly include exceptions.

As the federal state has the legislation and execution competence concerning labour law, **telework** is a policy to be introduced into federal law as well. In Austria, there basically exists no right to telework or “home office”. Instead, telework can be negotiated and agreed in writing in every company as an individual **agreement between the employer and the employee**. In addition, the framework conditions for home office can be defined in a **works agreement**. A next feasible step would be to standardise the framework conditions for home office as compulsory content of the **collective agreement**, as this is explicitly possible for other reasons contained in company agreements. It would also be possible, for example, to explicitly extend the collective agreement's definition of employees' rights and obligations to include "home office matters". The more complicated legal issues, however, only become apparent indirectly: For example, it is questionable to what extent the legally prescribed **occupational health and safety** or the regulations on (maximum) **working times** would be compatible with a right to home office. In addition, **data protection** regulations must also be observed by employees at home.

4.2.2 EU law – Federal law – Municipal law

Measures not only having to take into account both the level of European and national law, but also touching on municipal autonomy are the **reduction of public parking spaces, car-free city centres** and **lowered speed limits**.

Prima facie, traffic restrictions always are subject to the scope of the EU internal market, particularly the application of the free movement of goods or the freedom of services. However, according to the ECJ, this does not hold for all potential barriers which are “too uncertain and too indirect”. It could be argued that the establishment of car-free city centres or environmental zones remains below this threshold: After all, such a restriction only takes effect after the passenger car has been acquired - and therefore clearly is a mere modality of use – moreover and it is not related to any type of service. Last but not least, an environmental zone would only have a very limited local effect (Kröger, 2012). The same holds for the restriction of public parking spaces and specific speed limits. The fundamental freedoms are therefore not covered at all (*Ranacher*, 2001); the legal feasibility of such traffic restrictions thus depends solely on the prerequisites of national law.

The Road Traffic Act, which applies to all public roads, permits driving at certain speeds as well as permanent parking of passenger cars. If necessary, **driving can be prohibited, parking can be restricted and driving speeds can be limited in certain areas** by municipal regulation - e.g. to calm traffic, to keep certain dangers or nuisances away, but also to protect the environment. However, climate protection in particular has not yet been explicitly recognized as a criterion by the Austrian High Administrative Court (VwGH). Moreover, traffic restrictions could only be imposed in "certain" areas, i.e. areas that are clearly distinguished from other areas or roads, which would be hard to argue considering climate protection as a global phenomenon. Further, the Road Traffic Act requires traffic restrictions to be „necessary"; therefore, if a less restrictive means to achieve the objective was apparent, a corresponding regulation would be unlawful. Also, the authority would have to balance the public interest in the traffic restriction with the public interest in unhindered use of the road, and can issue a corresponding regulation only if the former outweighs the latter (Geringer and Romirer, 2019).

General speed limits, however, could not be established by ordinance at all, according to the Austrian Constitutional Court. Instead, the legislator would have to further reduce the speed limits prescribed in the law itself.

4.2.3 Federal law – Laender law – Municipal law

A **congestion charge** levied for using a passenger car in the city is a matter of mixed competences of Austrian authorities. In general, tax law provides exclusive municipal levies that can be regulated as such by the *Laender* in special *Laender* laws. However, some of these levies are already designated by the federal legislator as being reserved for municipalities; for example, fees for the use of municipal facilities and installations, i.e. also municipal roads, which constitute exclusive municipal levies. However, although such levies could, theoretically, be freely decided and decreed by the municipality, **road and bridge tolls** are expressly excluded from this rule. A congestion charge could therefore not be set autonomously by a municipality or city.

Concerning a possible **increase of parking fees** which is aimed at decreasing the traffic volume, municipalities are authorised to establish chargeable "short-stay parking zones" on roads that are not federal roads by federal law. Otherwise, municipalities are dependent on the provisions of a possible parking fee *Laender* law, as it exists (only) in Styria and Salzburg. Otherwise they are free in both setting a higher minimum charge and, for example, an exponential increase for longer parking periods – if only in compliance with the constitutional equivalence principle: A fee must be primarily committed to a fiscal purpose and the incentive aspect (here: to waiver the use of passenger cars) can only be added as a supplement. A significant increase in charges for climate protection reasons, while the counterpart (= the volume of parking spaces) remains the same, could therefore be unconstitutional.

4.2.4 Laender law – Municipal law

In regard to **reductions of private parking spaces**, legal requirements can be found in the building, regional planning or garage laws of the *Laender*. Using the example of Vienna, new buildings and building extensions are subject to a parking space obligation, which means that the builder must provide a sufficient number and size of suitable parking spaces. This obligation can be fulfilled either in kind or by payment of a compensatory levy. For spatially limited parts of the urban area, the obligation can also be reduced by up to 90% in the municipalities' development plans due to traffic, environmental policy objectives and other reasons.

Spatial planning is an essential instrument for the sustainable design of passenger transport, as the concept of the "**city of short distances**" illustrates: The guiding principle of a settlement structure within walking distance should prevent low settlement density which typically needs a high degree of motorisation (*Madner/Grob*, 2019). In this context, the interrelationships between transport, urban structure and land use are decisive. In particular, spatial planning and buildings laws which lie in the competence of the Laender and municipalities/cities are to be considered.

The spatial planning laws of the Laender all tendentially pursue the **(re)vitalisation of town and city centres**, i.e. a reversal of the ongoing trend towards the creation of "business parks" or shopping centres “in the green”, which undoubtedly favours motorised individual transport. According to the exemplary and recently amended Carinthian Spatial Planning act, the construction of shopping centres is, in general, only permitted in local or urban centres. Further possibilities that spatial planning could offer would be, for example, appropriately adapted designations of temporary building land dedications **to avoid the “building land paradox”**, which basically also favours urban sprawl. In addition, the limits for building density, height and permissible number of storeys could be adapted in the building laws.

5. Discussion

5.1 Quantitative effectiveness and transport system feasibility

The transport model VMÖ2025+ is the official Austrian national transport model. The model covers passenger and freight transport. Passenger transport is modelled according to the classic 4-step model: generation, distribution, mode-choice and network assignment (for full details see Supplementary Material, section A).

For the present analysis VMÖ 2025+ has been adapted beyond the year 2025. All relevant input data, such as population, motorization and goods transport have been updated to the year 2040. With the model parameters otherwise untouched a “business as usual scenario 2040” has been calculated.

The three policy package scenarios of the present analysis were modelled by adding the policy packages to the BAU (business as usual) scenario 2040. Due to the model structure of VMÖ model some measures were implemented directly and some measures had to be implemented by analogy. A minority of measures could not be implemented due to the model structure of VMÖ model. **Fehler! Verweisquelle konnte nicht gefunden werden.** shows traffic volume in the three scenarios in the year 2040 as distance travelled per year.

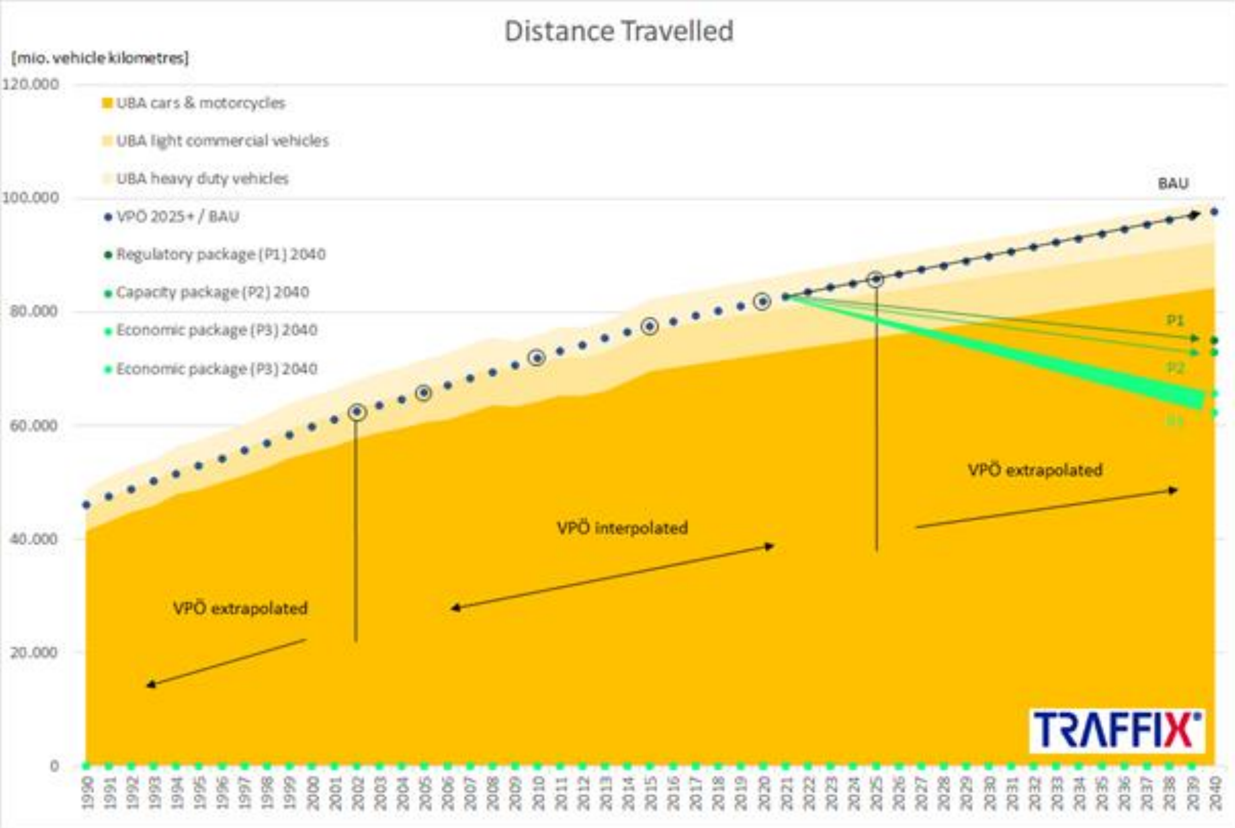

Figure 4: Austrian transport volume: Distance travelled per year, for BAU and three policy packages up to 2040

The regulatory package (P1) would reduce distance travelled per year by 23% by the year 2040 compared to the business as usual scenario. The capacity package (P2) would reduce distance travelled per year by 25%, and the economic package by 33% to 36%, depending on the specific design of CO_2 tax, respectively.

5.2 Evaluation of emissions

The conversion of the transport performance calculated with the transport model as described in section 5.1 into transport emissions is carried out using the Network Emission Model (NEMO) in the latest program release. NEMO is the tool used for the mandatory annual compilation of the official Austrian air pollutant and greenhouse gas inventory in the transport sector. In addition, NEMO is used to create development scenarios with time series up to 2050, which show transport emissions as a result of different measures and ambition levels.

The traffic forecast (VPÖ2025+) including the associated transport model and the transport emission model, which is used for calculating the yearly Austrian air pollutant and greenhouse gas inventory show a very high consistency in their results and are thus a solid basis for modelling the effects of the analysed policy packages.

The individual measures in the policy packages were divided into mainly activity-related and mainly fleet-related measures. Mainly activity-related measures primarily affect transport performance and thus traffic volume and are quantified in the transport model and over-calculated in the emissions model in terms of ecological effects. Mainly fleet-related measures affect the composition of the vehicle fleet (e.g. higher share of zero-emission vehicles) and are mapped directly in the emission model in terms of their ecological impact. The specific allocation is listed in the Supplementary Material section BTransport emissions modelling.

Figure 5 shows the results of the emission modelling both, with an activity-related measure only and with activity and fleet-related measures for all three policy packages.

In the reference scenario BAU, passenger transport emits 6.9 million tonnes of CO_2 equivalents in 2040. By reducing traffic volumes as a result of the activity-related measures only, these emissions could be reduced to 5.1 to 4.8 million tonnes of CO2 equivalents (-26.1% to -30.4%). If the fleet-related measures, which are identical in their effect in policy packages one and two, are also taken into account, emissions can be reduced to 0.4 million tonnes of CO2 equivalents (-94.2%). The residual emissions in both policy packages result from the vehicle categories buses and motorised two-wheelers, which were not examined. If similar measures were taken here, the emissions from passenger transport could be completely eliminated.

As mentioned earlier, the exact design of the tax reform was not defined in Policy Package 3, which is why no further reduction potential is shown in the figure. However, through appropriately restrictive fiscal measures that result in a rapid and comprehensive electrification of the vehicle fleet, emissions could also be reduced in policy package 3 to a similar extent as in policy packages 1 and 2. A reduction of greenhouse gases of up to 80 % of the potential of the policy packages 1 and 2 is seen as possible.

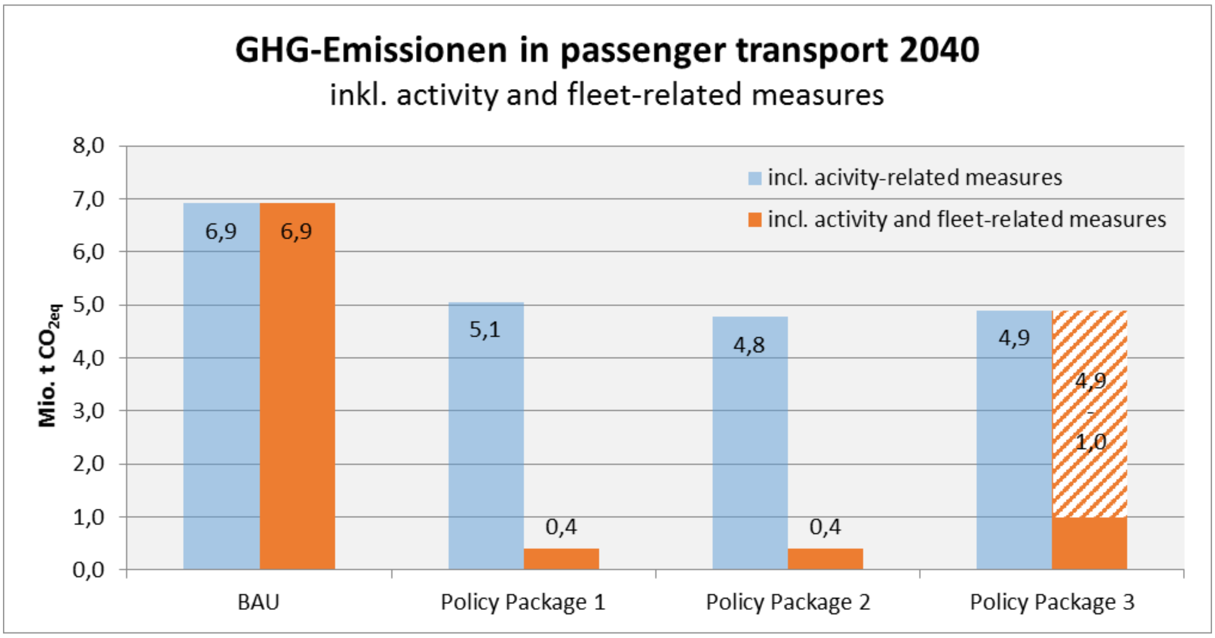

Figure 5: results of the emission modelling in terms of GHG-emissions

5.3 Total social costs

The decarbonization of passenger transport affects the level and composition of societal costs for mobility. We have therefore calculated the different types of costs for various means of ground-based transport and developed a 2040 Baseline scenario as well as three decarbonized scenarios following the Improve-Shift-Avoid approach (Banister, 2008) . The costs of the following modes of transport (and respective subspecifications) were considered: Firstly, within the category of car transportation we distinguished between three sizes of cars (small, medium, large) and between three different kinds of propulsion (petrol, diesel, electric), respectively. Secondly, within the category of public transport we investigated costs of city trains and long-distance trains, city buses and intercity buses, as well as tram and subways. For busses and trains we again differentiated between diesel and electric propulsion. Thirdly, active mobility, comprising walking, biking, and e-biking. In terms of types of costs, we estimated net vehicle costs that comprise capital expenditures and other fixed costs, such as insurance or parking, and operating expenditures including energy, maintenance and repair, and in case of public transport also personnel costs. For e-vehicles, we considered learning curve effects based on Kittner et al. (2020). All vehicle costs were calculated on a net basis, i.e. without taxes and without subsidies, as we are interested in the total social costs, where taxes and subsidies are only transfers among agents not changing overall costs. Secondly, we calculated external costs for accidents, air pollution, climate change, noise, well-to-tank-emissions, habitat damage based on Essen et al. (2019), barrier effect (Litman et al., 2019), health benefits (Gössling et al., 2019, and congestion-borne travel time costs based on Schmid et al. (2019)). Thirdly, we calculated travel time costs, representing the monetary value of time spent on travel, for which the values of travel time savings are based on Schmid et al. (2019) and average speeds are derived from Tomschy et al. (2016). Due to the considerable uncertainty in the calculation of the costs for the year 2040, we used a Monte Carlo simulation, for which we varied input variables within plausible bandwidths.

The results show that total social costs of mobility will decline when taking decarbonization measures compared to a business as usual scenario. The electrification of cars and diesel-powered public transport as an improve measure will lead to a reduction in total net vehicle costs spent across all transport modes in 2040 due to learning curve effects. External costs will also be significantly reduced by avoiding fossil fuels. The travel time costs, in contrast, remain unchanged, as we have assumed that average speeds will remain the same. When additionally, trips are shifted away from car use towards public transport and active mobility, total social costs are further reduced. Net vehicle costs decrease and external costs are even overcompensated by the positive health effects of active mobility. Only time costs increase due to the lower travel speed of most public transport and especially active mobility. However, note, that we have not assumed adjustments in infrastructure (e.g. cycle highways) or provision of public transport (e.g. higher service interval, PT in rural areas) which could substantially reduce travel times of these modes in a decarbonized transportation system. Lastly, avoid strategies lead to a reduction of overall mileage travelled, resulting in a decline of total social costs of mobility. Overall, the combination of Improve, Shift and Avoid strategies faces the lowest societal costs of mobility. Furthermore, the altered composition of total social costs, i.e. lower net vehicle costs and external costs, higher travel time costs, in a decarbonized transportation system is beneficial to our society. First, the reduction of external effects has a positive effect on Austria's public health, air quality and natural systems. Second, lowering direct monetary costs and increasing travel time costs make transportation inclusive for all households. Access to transportation is then more a matter of time than of financial resources. Hence, the accessibility to transportation is increased when considering that the time budget is equal for every human being, while financial resources highly depend on one's life circumstances. In summary, we find that the decarbonization of ground-based passenger transport leads to a substantial reduction in societal mobility costs (for details see Maier et al., 2021). The argument that decarbonization is too expensive is thus invalidated; it is rather a matter of putting together and implementing the right policy bundles and sharing the resulting costs in a fair way.

5.4 Distributional and employment effects

We further investigated this cost sharing within the Austrian economy in terms of distributional household effects as well as employment effects.

When quantitatively investigating a sub-group of the relevant policies for their distributional implications by applying a computable general equilibrium (CGE) model we find the following: We compare a mandated phase-out of conventional cars to a scenario including road pricing, and to a policy package including additional soft measures to raise public acceptance and to further support a modal split shift in favour of public transport. A mandated phase-out would be beneficial mostly for high-income households in all residence locations and medium-income households living in the periphery. The remaining groups of households are worse off, particularly households living in urban areas. However, such potential distributional conflicts vanished once road pricing and further soft measures were added to the policy mix, again underlining the need policy packages in contrast to the introduction of single policies (for further details see Dugan et al. (2021)).

From an employment perspective, several aspects need to be considered for a transition to a climate neutral transport system. First, the speed of transition of the transport system within Austria matters but also how fast a transition in the rest of the world takes places. This is relevant as infrastructure and renewable energy provision for a transition in Austria has also job implications mainly within Austria. Vehicle manufacturing on the other hand is strongly export oriented and not especially aligned towards ZEVs in Austria (Steininger et al. 2021, Gabelberger et al. 2020). Furthermore, the share of automotive industry in gross value added in Austria is relatively small and below the European average (Transport and Environment, 2018). Thus, a global transition of the transport system will have only small employment impacts in Austria from reductions in traditional car manufacturing. At the same time employment opportunities emerge in renewable electricity and infrastructure provision as well as in the area of public transport. For this last area it has been shown that Austria has strong competences in manufacturing, especially for rail transport industries (Steininger et al. 2021) and thereby could profit from a faster global transition. Accounting for these positive and negative sectoral effects Großmann et al. (2020) show that a transition could have overall small positive employment effects for Austria, however the shift between sectors and skill demands will be quite strong. A policy package for passenger transport therefore needs to be accompanied by a farsighted qualification strategy, taking into account an overall transition to a climate neutral economy. Thereby employment reduction from reduced mobility demand and conventional vehicle manufacturing can be compensated in other sectors. A qualification strategy would have to ensure such transition of employees between sectors, skill demands and regional scopes. Considering the relatively short transition phase until 2040 and training periods of e.g. 3-5 years for science, technology, engineering, and mathematics (STEM) jobs, rather strong measures are needed to ensure a proper provision of necessary skills.

5.5 Public acceptance and how it differs across push measures

Another relevant aspect already mentioned in section 2 is the public acceptance of such policy packages, as it is one critical factor that can hamper or even fully interrupt policy implementation. While pull measures, such as the expansion of public transport, are traditionally more accepted, push measures often lack acceptance. However, people rate push measures differently, depending for example on the type of measure (such as regulatory, capacity-restricting, or economic), or whether they consider them to be fair or effective

Based on results of a conjoint experiment (Thaller et al., 2021b, Figure 2), we find that regulatory measures, such as banning the registration or use of internal combustion engines and hybrid vehicles, are evaluated more positively than economic measures, such as increasing gasoline or parking fees The most favored push measure was a registration ban for ICEVs and interestingly, we found study participants to prefer the introduction of such driving bans even compared to the implementation of no measures at all, indicating higher support for the regulatory package. However, one has to take into account that we did not include information on how the money will be spent, where research finds higher acceptance for economic measures once earmarking is in place. Thus, that under the above setting regulatory measures have been found to be better accepted than economic measures could change once earmarking and transparent communication about the revenue use of economic measures is in place. This constitutes a highly relevant field for future research.

6. Conclusions

A transport policy that meets the requirements of an effective greenhouse gas reduction while at the same time achieving political acceptance will have to rely on a combination of a wide-ranging bundle of measures. This will not only enable a country like Austria to achieve its climate goals (in the particular example climate neutrality by 2040) in the transport sector, but will also lead to improvements in many other dimensions that represent societal and social goals, such as improved health, reduced noise pollution, reduced congestion, and increased safety.

Replacing all cars using an internal combustion engine with electric cars is necessary for the decarbonization of our mobility system. However, this change alone is not enough to achieve truly sustainable mobility. E-mobility also leads to a lower cost per kilometer and thus incentivizes an increased use of the private vehicle stock. Consequently, other problems that are caused by our traffic system (e.g. congestion, particulate matter, other emissions and pollution) may be amplified. Furthermore, the increasing demand in electrical energy and resources in manufacturing will be significant and difficult to meet using sustainable sources. Thus, also policies that aim at shifting traffic away from the use of a private car as well as enable the avoidance of trips altogether are paramount for a sustainable traffic system.

If beyond technological improvements in the transport sector also mode shifts towards sustainable means of transport are induced and systemic support is given to avoid journeys, e.g. by adequate spatial planning or appropriate framework conditions for teleworking, we find that the overall social costs of mobility also fall and transport becomes more socially acceptable.

Push measures find higher acceptance when presented and implemented as part of a policy package together with pull measures. Therefore, framework and communication are key factors in the implementation of measures.

Agency to act is required at all levels, and in consistent interaction. For example, a ban on the registration of internal combustion engines requires a corresponding framework at the EU level, and the interaction of federal tax policy and the organization of public transport (predominantly at the subnational level) is required to provide incentives for a switch to environmental transport.

The conversion of the mobility system is also related to a climate-neutral conversion of the entire economy, which concerns, for example, the provision of renewable energies for electrification as well as housing regulations and mobility aspects in spatial planning. While a climate-neutral transition is associated with neutral to positive employment effects, transitions between sectors and changes in skill requirements can be significant. For the conventional car industry in particular, appropriate and far-sighted measures need to be taken to avoid additional unemployment due to mismatches in labor supply and demand for certain sectors and skills.

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Supplementary Material

A. VMÖ 2025+ (Verkehrsmodell Österreich) and concordance between transport and emissions model

VMÖ 2025+ is the official Austrian national transport model. It has been developed by a consortium led by TRAFFIX (former Trafico) within the context of the national traffic forecast Verkehrsprognose Österreich 2025+[1]. The model has been used by main Austrian transport actors, such as the Federal Ministry of Climate Action, Energy, Mobility and Innovation, the Austria road authority ASFINAG, Austrian Railways ÖBB and Austrian Railway Infrastructure company SCHIG.

The model consists of a multimodal network model and of traffic demand models for both, passenger and freight transport (see Figure A.1).

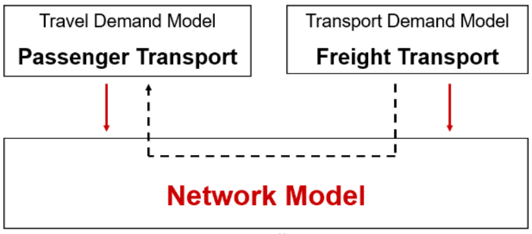

Figure A.1: General structure of VMÖ model

The spatial scope of VMÖ covers Austria and its neighboring countries. The VMÖ network model consists of 2’628 traffic zones (2’412 within Austria) and 44.554 links (30.699 within Austria). The network contains within Austria all motorways, arterial roads and collectors as well as main local roads. Rail infrastructure in Austria is covered completely within the model.

Passenger transport is modelled according to the classic 4 step–model as shown in Figure A.2.

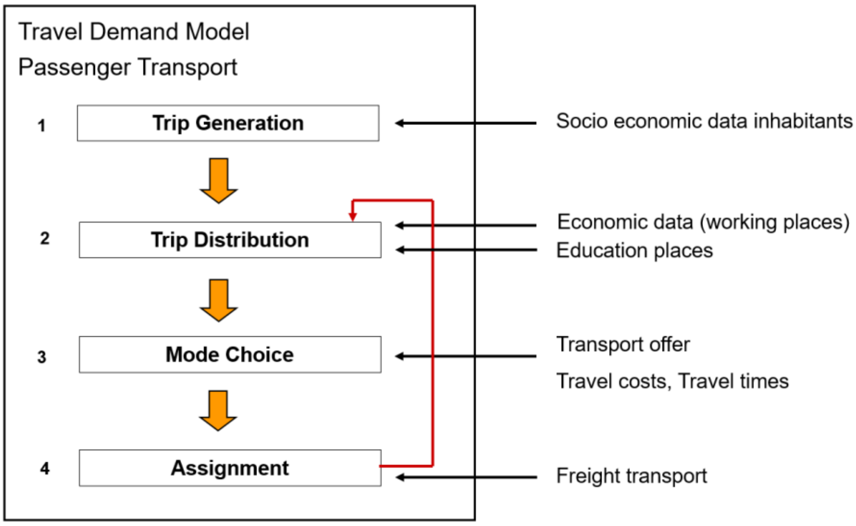

Figure A.2: Structure of the VMÖ travel demand model

[1] Käfer A. et al.: Verkehrsprognose Österreich 2025+, Studie i.A. von BMVIT, ASFINAG, ÖBB, SCHIG, Endbericht, Wien, 2009

The VMÖ modelling approach is disaggregated, with 40 homogenous socioeconomic groups, 4 spatial structure types, 5 modes of transport (pedestrian, bicycle, public transport, car-driver, car-passenger) and 16 different trip purposes being distinguished.

The mode choice model is based on the relevant influencing variables with the following probability of choosing a certain mode:

$$Pij(m,g,z) = \frac{e^{ß \,.\, b(T,Uij(m,g,z))}}{\Sigma\, e^{ß \,.\, b(T,Uij(m,g,z))}}$$

The main components are as follows:

- *Time for access and egress*
- *In-vehicle travel time*

Costs

- *Car: variable travel costs, parking costs, tolls*
- *Public transport: average tariffs per group and trip purpose*

Public transport - specific:

- *waiting time at the start*
- *frequency of transfers*
- *transfer walking time*
- *transfer waiting time*

Demand is segmented by travel purpose and homogeneous travel group (eg. income class, car availability). For each segment a different parameter set is used in the utility function to determine mode choice. The parameters governing the effect of the demand variables are based on mobility survey data. In total there are 2’560 different parameter sets (40 x 4 x 16), mode choice is therefore the sum of mode choice in each of the 2’560 segments.

The main characteristics of VMÖ are as follows:

- *VMÖ provides a highly detailed segmented approach in form of homogenous socioeconomic groups, spatial types and trip purposes within the inner study area (Austria).*
- *VMÖ works according to the classic 4-step model with realistic model reactions in every step of the modelling process.*
- *VMÖ includes passenger and freight transport and therefore provides realistic road demand levels.*

For the present analysis VMÖ 2025+has been adapted beyond the year 2025. All relevant input data, such as population, motorization and goods transport have been updated to the year 2040. With the model parameters otherwise untouched a “business as usual scenario 2040” has been calculated.

A comparison with the calculations of Environment Agency Austria (Umweltbundesamt – UBA, scenario WEM17 – “with existing measures”) shows good concordance in terms of annual distance travelled (see Figure A.3).

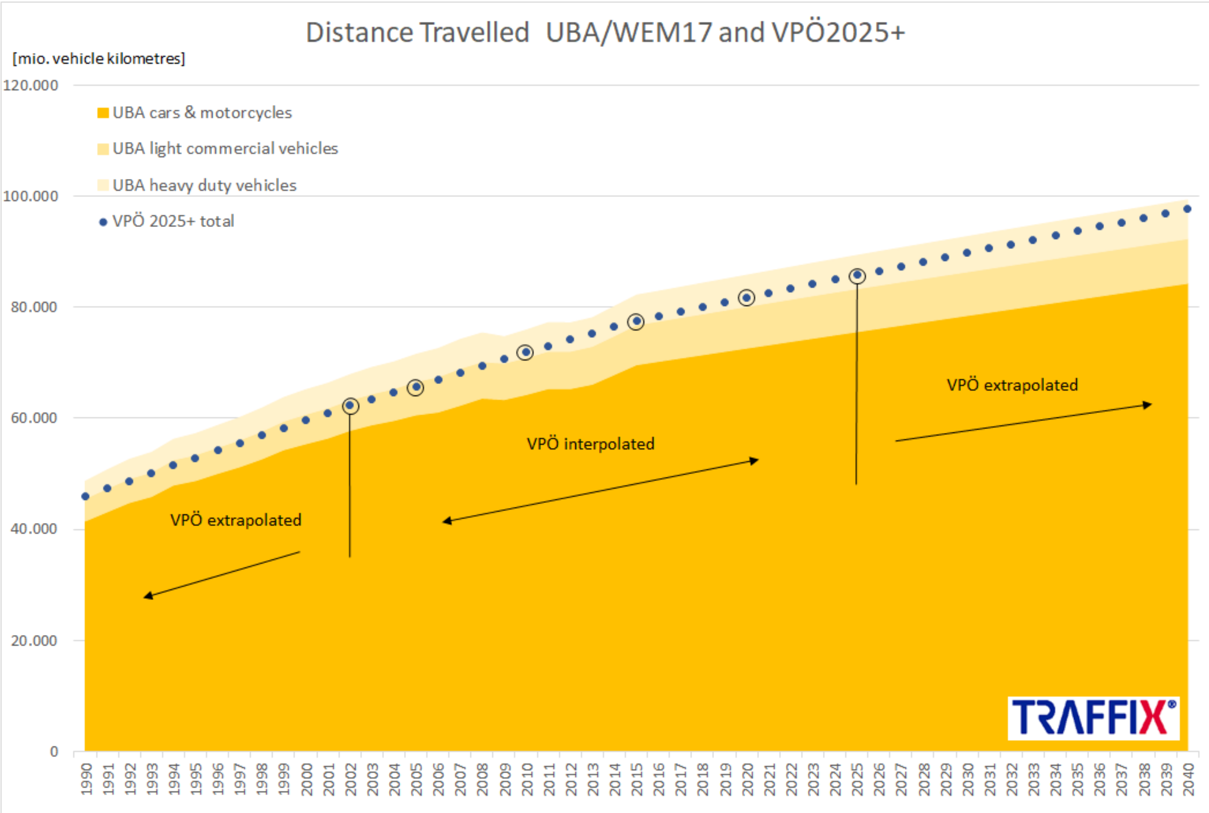

Figure A.3: Structure of the VMÖ travel demand model

The timeline between 2020 and 2040 shows even decreasing marginal deviations towards the end of the forecast.

Implementation of Policy Packages

The three policy package scenarios of the present analysis were modelled by adding the policy packages to the BAU (business as usual) scenario 2040. Due to the model structure of VMÖ model some measures were implemented directly and some measures had to be implemented by analogy. A minority of measures could not be implemented due to the model structure of VMÖ model. Direct implementation applies to measures [6], [9], [10] and [12], indirect implementation to measures [1] to [5], [7] and [8], [11], and [22] to [23] (numbering as in Table 1 in main text).

B. Transport emissions modelling

NEMO was developed at the Institute for Internal Combustion Engines and Thermodynamics (IVT) at the Graz University of Technology (TUG) as tool for the simulation of transport related emissions in road networks. NEMO combines both detailed calculation of the vehicle fleet composition and simulation of emission factors on a vehicle level. NEMO calculates the percentages of different vehicle layers on the overall traffic volume as a function of year and considered road type based on data on vehicle stock, composition of new registrations and vehicle usage.

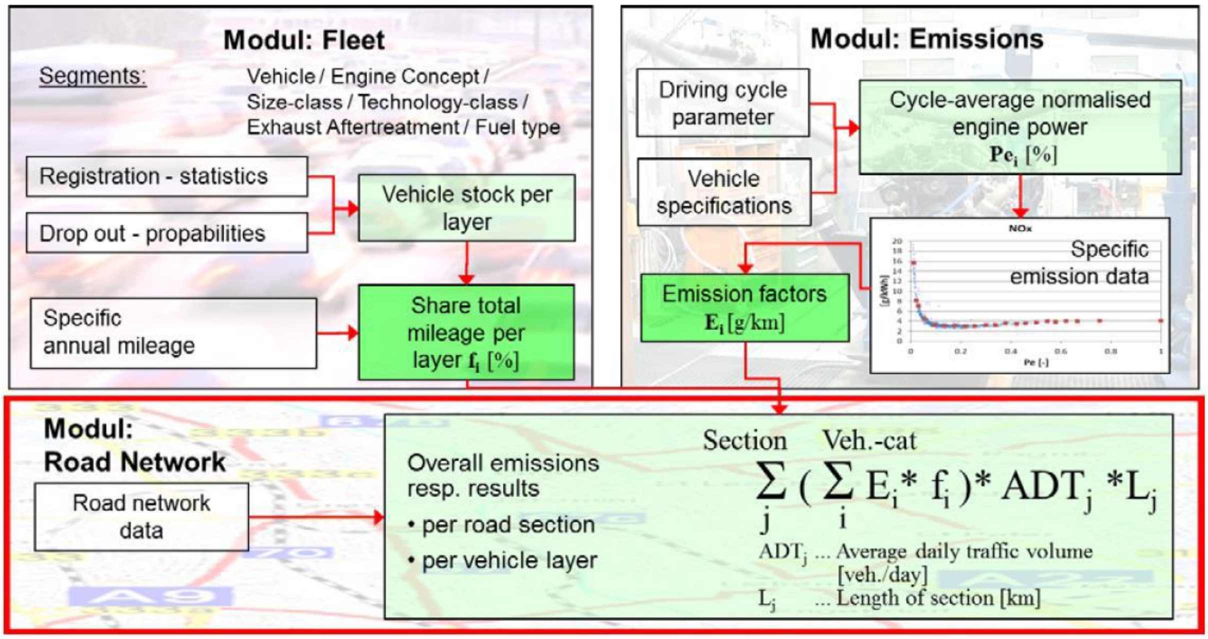

Figure B.1: Schematic picture of the structure from NEMO

In the current use case, the overall traffic volume was taken from the upstream work with the transport model. For this purpose, a list with all edges of the transport model graph with associated traffic volume and average speed per scenario was taken over as the result of the transport model, prepared at the interface for incorporation into NEMO and read in. Subsequently, fleet-relevant measures were modelled and finally the transport emissions per scenario were calculated. Workflow and results are explained in detail below.

In the first step, the reference scenarios were compared, i.e. without taking the defined policy packages into account, in order to be able to develop a consistent starting point for the modelling. For this purpose, the traffic volume of the reference scenario from the transport model, *Business as Usual* (BAU), was compared with the traffic volume of the reference scenario from the emission model, *With Existing Measures* (WEM), both for the year 2040. Taking into account the fact that not all vehicle categories are represented in the transport model - buses and motorised two-wheelers are not taken into account - the first comparison already showed a high degree of agreement: 97.8 billion vehicle kilometres were mapped with the transport model, this traffic volume was "translated" into 98.0 billion vehicle kilometres with the emission model and finally extrapolated to 100.5 billion vehicle kilometres with the missing vehicle categories.

Table B.1: results of the alignment transport and emission model

		VMÖ 2025+	NEMO
		[million vehicle kilometres]	
Passenger transport	Busses	-	700
	Motorised two-wheelers (M2W)	-	1 820
	Passenger cars	89 810	79 900
Freight transport	Light duty vehicles (LDV)		9 100
	Heavy duty vehicles (HDV)	7 850	9 010
Total (excl. Busses, M2W)		**97 660**	**98 010**
Total			**100 530**
WEM (2017)			**97 430**
WEM (2019)			**105 150**

This compares to 97.4 billion vehicle kilometres according to scenario WEM from 2017 (-3.1%) and 105.2 billion vehicle kilometres according to scenario WEM from 2019 (+4.7%). For this reason, the modelling team did not see any need for a further adjustment of the model references.

The allocation to mainly activity-related measure and mainly fleet-related measure is as follows:

Mainly activity-related measures

- [3] Management and reduction of parking areas (P1)
- [5] Car-free city centers (P2)
- [6] Conversion and reduction of road infrastructure (P2)
- [8] Congestion charge for city centers (P3)
- [9] Reduction of speed limits (P1-P3)
- [10] Road Pricing (P1-P3)
- [11] Socio-ecological redesign of commuting allowance system [16] Raising awareness for alternative mobility modes (P1-P3)
- [12] User orientation of public transport (P1-P3)
- [13] Public transport kick and guarantee (P1-P3)
- [14] Carpooling/-sharing, on-call bus and share taxis (P1-P3)
- [15] Regional development and planning (P1-P3)
- [16] Raising awareness for alternative mobility modes
- [17] Support of non-motorised private transport (P1-P3)
- [18] Intelligent technologies and digitalization
- [21] Company mobility Plans (P1-P3)
- [22] Teleworking (P1-P3)
- [23] Mobility efficiency act (P1-P3)

Mainly fleet-related measures:

- [1] Stop new admission of fossil fueled cars (P1)
- [2] Ban on the use of fossil fueled cars (P1)
- [4] Restriction on the overall admission and operation of fossil fueled cars (P2)
- [19] Electrification of individual motorized transport (P1-P3)
- [20] Electrification of public transport (P1-P3)

both activity and fleet-related measure

- [7] Ecological tax system (P3)

For the modelling of the fleet-related measures, the following assumptions were made and impacts derived:

Table B.2: assumptions and derivatives for the emission modelling regarding fleet-related measures

Policy Package 1	***Policy 1: Stop new admission of fossil fuelled cars*** From 2025, no new passenger cars with combustion engine may be newly registered anymore. This will result in a combustion engine old vehicle-stock of 30% to 40% in 2040. No impact on other vehicle categories.
	Policy 2: Ban on the use of fossil fuelled cars From 2040 onwards, no passenger cars with combustion engine may be operated anymore (incl. HEV, PHEV, REX). No impact on other vehicle categories.
	➔ **Policy 1 ist required for policy 2** ➔ **Effect of Policy 2 overlays effect of Policy 1**
Policy Package 2	***Policy 4: Restriction on overall admission and rides of fossil fuelled cars*** From 2040 onwards, no passenger cars with combustion engine (incl. HEV, PHEV, REX) may be newly registered anymore; From 2040 onwards, cars with combustion engine (incl. HEV, PHEV, REX) may no longer be operated. The effect of the mileage restriction overlays the effect of the registration restriction (cars with combustion engine can still be newly registered in 2039, but can no longer be operated in 2040). No effects on other vehicle categories.
	➔ **Identical impact like policy package 1** ➔ **No combustion engine passenger cars from 2040 onwards**
Policy Package 3	***Policy 7: Ecological tax system*** There are no fleet-related measures that can be directly modelled with the emission model. Thus, the effect can only be estimated within the framework of post-processing the results of the original emission modelling. However, the concrete design of the tax system hasn't been designed.
	➔ **No impact calculated or estimated in the course of the emission modelling**
All policy packages	***Policy 19: Electrification of individual motorized transport*** The ramp-up of electric mobility in the passenger car sector will be promoted between 2019 and 2021 through purchase subsidies for charging stations and vehicles. The measure is already largely included in the WEM 19 scenario; no significant additional potential is expected.
	Policy 20: Electrification of public transport The ramp-up of electric mobility in the public sector is promoted through further electrification of the ÖBB route network, the procurement of zero-emission vehicles and corresponding purchase subsidies. The measure is already partly included in the scenario WEM 19. The expected additional potential is low and has not yet been quantified.