PUBLIZIERBARER ENDBERICHT

A) Projektdaten

Kurztitel:	STEP
Langtitel:	Supporting technological and market success for low-carbon vehicle propulsion [Instrumente für die Markteinführung von CO_2-armen Antriebstechnologien für Fahrzeuge]
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Projekt- und KooperationspartnerIn (inkl. Bundesland):	Institut für Verbrennungskraftmaschinen und Thermodynamik, Technische Universität Graz (Stmk)
Schlagwörter:	technologischer Wandel, alternative Antriebe, Elektroauto, Politikszenarien
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B) Project overview

1 Executive Summary

STEP untersuchte das Marktpotenzial alternativer Antriebstechnologien in Österreich für den Zeitraum bis 2020 und bis 2050. Ausgehend von der Zielsetzung einer breiten Marktdurchdringung verschiedener innovativer Technologien, die eine deutliche Reduktion von Treibhausgasemissionen im Verkehrssektor erreichen könnten, werden sowohl endogener technologischer Wandel als auch der gezielte Einsatz von Politikinstrumenten in verschiedenen Phasen der Entwicklungsprozesse der verschiedenen Antriebstechnologien betrachtet.

Der methodische Zugang von STEP integriert eine Trendschätzung der Fertigungskosten für alternative Antriebstechnologien, ein ökonomisches Modell zur Technologieentwicklung, ein Flottenmodell für die Entwicklung des Fahrzeugbestandes sowie eine Nutzerbefragung zu Elektrofahrzeugen. Neben einem Business-as-usual Szenario, das die Technologieentwicklung bis 2050 trendmäßig fortschreibt, werden sieben Politikszenarien untersucht, die den Fortschritt alternativer Fahrzeugtechnologien begünstigen könnten. Nachdem der Markterfolg von Elektromobilität noch fraglich ist, wurden begleitend vier strategische Szenarien ausgearbeitet, die mögliche „Zukünfte" von Elektrofahrzeugen beschreiben.

Die technologischen Lernkurven zeigen, dass elektrische Fahrzeuge (electric vehicle EV) wettbewerbsfähig mit anderen Antriebstechnologien in Österreich werden, sobald gemeinsam mit einer weltweiten Einführung von Elektromobilität die globalen Produktionskosten sinken. Der elektrische Antrieb und die Batterie stellen die größten Kostenkomponenten am EV dar, so dass hier hohe Lernraten durch technologischen Fortschritt zentral sind. Plug-in Hybridfahrzeuge (plug-in hybrid electric vehicle PHEV) können als Übergangstechnologie fungieren, da ihre technologischen Komponenten sehr ähnlich zu Autos mit Verbrennungskraftmotoren (internal combustion engine ICE) sind. Aufgrund ihrer hohen Materialkosten zeichnet sich für Fahrzeuge mit Wasserstoffantrieb (fuel cell electric vehicle FCEV) derzeit keine Konkurrenzfähigkeit mit EV innerhalb der nächsten Jahrzehnte ab.

Die EU-Emissionsziele fordern für Österreich einen Reduktion um 16% der Treibhausgasemissionen im Zeitraum 1990-2020 in Sektoren wie dem Transportsektor, die nicht im Emissionshandelssystem ETS enthalten sind, und von -80% insgesamt im Zeitraum 1990-2050. In einem Business-as-usual-Szenario (REF) werden diese Ziele im Personenverkehr nicht erreicht, da STEP eine Veränderung der CO2-Emissionen für 1995-2020 um +10% und für den Zeitraum 1995-2050 um -42% vorhersagt. Die Problematik zu hoher CO2-Emissionen im Transportsektor wird sich folglich nicht „von selbst", ohne gezielte Politikintervention lösen, da der autonome technologische Wandel zu schwach ist, um die Emissionsziele zu erreichen.

Das strengste Politikszenario in STEP, das Auslaufen von ICE durch die Einführung strikter Emissionsstandards für Fahrzeuge (PhaseICE_RD), erreicht eine Veränderung der CO2-Emissionen für 1995-2020 um +1% und für 1995-2050 um -46%. Auch dieses Szenario erfüllt nicht die EU-Emissionsziele. Wenn PhaseICE_RD jedoch um weitere Politikinstrumente zur Förderung von umweltfreundlichem Personenverkehr ergänzt wird, könnten die Emissionsziele erreicht werden. Alle anderen untersuchten Politikszenarien erreichen schwächere Emissionsreduktionen.

Unter der Annahme, dass grüne, mit geringem CO2-Ausstoß produzierte Elektrizität in Österreich von 2005-2050 verfügbar ist, könnten die EU-Emissionsziele eher erreicht werden. CO2-Emissionen in REF verbleiben bei +10% bis 2020, da bis dahin elektrische Antriebe kaum am Fahrzeugmarkt vertreten sind, erreichen aber -73% im Jahr 2050. PhaseICE_RD erreicht -10% bis 2020 und -80% bis 2050. Auch die meisten anderen Politikszenarien erreichen unter der Annahme grüner Elektrizität zumindest -76% in 2050.

Insgesamt sind die Unterschiede im Jahr 2050 zwischen dem Referenzszenario REF und den Politikszenarien eher gering. Alle Politikszenarien können ICE schneller aus dem Markt drängen, als das in REF geschehen würde. PHEV haben durchwegs einen Status als Übergangstechnologie, die den Markteintritt von EV vorbereitet. Die Adoption von EV unterscheidet sich nicht wesentlich zwischen den Szenarien, ist aber am schnellsten bei

Einführung einer Treibstoffsteuer: Nachdem EV keine fossilen Treibstoffe benötigen, können sie dann ihren Kostennachteil gegenüber PHEV deutlich schneller überwinden. FCEV schaffen nur mit umfangreichen Subventionen den Markteintritt; ohne politische Intervention würden FCEV nicht bis 2050 wettbewerbsfähig gegenüber anderen Antriebstechnologien werden.

In der Analyse strategischer Szenarien zur zukünftigen Marktentwicklung von Elektromobilität wurde eine „Schwarzer Schwan"-Situation festgestellt, in der eine erfolgreiche hochinnovative Technologie unerwartet in den Markt eintritt. Eine Fallstudie beschreibt den massiven technologischen Durchbruch bei Batteriekapazität von EV, der bei der kürzlich eingeführten Tesla Model S Limousine erreicht wurde, ein Luxusfahrzeug aus dem oberen Preissegment, das gängige Erwartungen an ein Elektrofahrzeug als klein, eng und unpraktisch durchbricht. Falls sich diese Technologie längerfristig in der Praxis bewährt und in Nicht-Luxus-Marktsegmente übernommen wird, könnte diese Innovation einen deutlich beschleunigten Markteintritt von EV ankündigen.

Eine Befragung unter Early Adopters, die eine öffentliche Förderung für den Kauf eines Elektrofahrrades erhielten, zeigt, dass diese Personen vorwiegend 60 Jahre oder älter sind und ihr E-Bike für Freizeitwege nützen. Mehr als ein Viertel der alltäglichen Wege werden zwar mit dem E-Bike unternommen, die Nutzer wechselten aber meist von anderen umweltfreundlichen Verkehrsmitteln (öffentlicher Verkehr, konventionelles Fahrrad) auf das E-Bike und reduzierten nicht ihre Autonutzung. Early Adopter haben typischerweise umweltfreundliche und technikaffine Einstellungen. Nachdem die meisten Haushalte vor dem Erhalt der Förderung kein E-Bike besaßen, dürfte die Förderung die Marktdiffusion von E-Bikes unterstützt haben. Die Anzahl an fossil betriebenen Autos und Motorrädern blieb jedoch in den meisten Haushalten konstant.

Vorrangiges Nutzungsmotiv für das E-Bike ist die wahrgenommene Nützlichkeit, die ihrerseits von einer einfachen Handhabbarkeit, einer fahrradfreundlichen Infrastruktur und den Einstellungen zu Umweltschutz und persönlicher Gesundheit abhängt. Im Vergleich zwischen Wegzwecken zeigt sich, dass Unterstützung durch das soziale Umfeld und persönliche ökologische Normen die Nutzung auf Arbeits- und Einkaufswegen fördern, während Freizeitwege mit dem E-Bike vorrangig von Einstellungen zu persönlicher Gesundheit abhängen.

STEP verbindet Modelle zu detaillierten Lernkurven, technologischem Wandel und Markteintritt von neuen Technologien sowie zur Durchdringung der Fahrzeugflotte und resultierenden CO2-Emissionen. Diese innovative Modellstruktur kombiniert sich gegenseitig ergänzende Zugänge, welche die jeweiligen Schwachpunkte der Einzelmodelle kompensieren können. Die integrative Perspektive auf technologischen Wandel von Fahrzeugtechnologien erlaubt die Bewertung politischer Maßnahmen und Handlungsoptionen in unterschiedlichen Entwicklungsstadien der einzelnen Technologien.

2 Project objectives

This synthesis report summarizes and discusses overarching results from the STEP project. For specific details, see the respective project deliverables (listed in section 7).

Transport is one of the main sources of pollution and greenhouse gas emissions in Austria. Moreover, transport shows by far the highest growth rate in greenhouse gas emissions compared to other sectors. One strategy to reduce greenhouse gases from passenger transport is innovation in vehicle propulsion technologies. Alternative propulsion technologies have the additional advantage that they hardly force individuals to change their mobility habits even for strict greenhouse gas targets as these technologies are close to CO2 neutral.

A range of environmentally friendly propulsion technologies exists (e.g., pure electricity, hydrogen) that have the potential to enter the mass market in the near future or in the long run. For ensuring that Austria achieves the emission targets of the EU, policy design has to consider different stages of the development process of alternative propulsion technologies (research and development, demonstration, deployment and commercialization) in order to promote competitiveness and a faster market entrance.

STEP analyzed the potential of alternative propulsion technologies in the Austrian vehicle market for the time horizon 2020-2050. Aiming for a broad market penetration of various innovative technologies and thereby substantial greenhouse gas reductions in the transport sector, both endogenous changes and promotion through policy instruments in different development stages of alternative propulsion technologies were investigated.

3 Project content and results

Research design

STEP integrated an estimation of cost trends in alternative transport technologies, an economic model of technological change, a model of vehicle stock turnover, and a survey on user reactions to the e-vehicle technology:

- Learning curves described current and future production costs of vehicle components as well as operational costs of various vehicle types (Vehicle Technology and Cost Model VeTCoM).
- The economic dynamic computable general equilibrium (CGE) model illustrated policy impacts on technological progress, market uptake, macroeconomic and distributional effects.
- The Network Emission Model (NEMO) simulated the gradual penetration of the entire vehicle fleet with new technologies and subsequent impacts on emissions and energy consumption.
- A survey among recent buyers of electric vehicles complemented the above models by investigating determinants of the adoption as well as the social diffusion of new technologies.

The dynamic modeling framework illustrated feedback effects between sectors and technologies, discontinuous growth, as well as rebound effects. We abbreviate the studied technologies as follows: ‘internal combustion engine” (ICE), “plug-in hybrid electric vehicle” (PHEV), “electric vehicle” (EV) and “fuel cell electric vehicle” (FCEV).

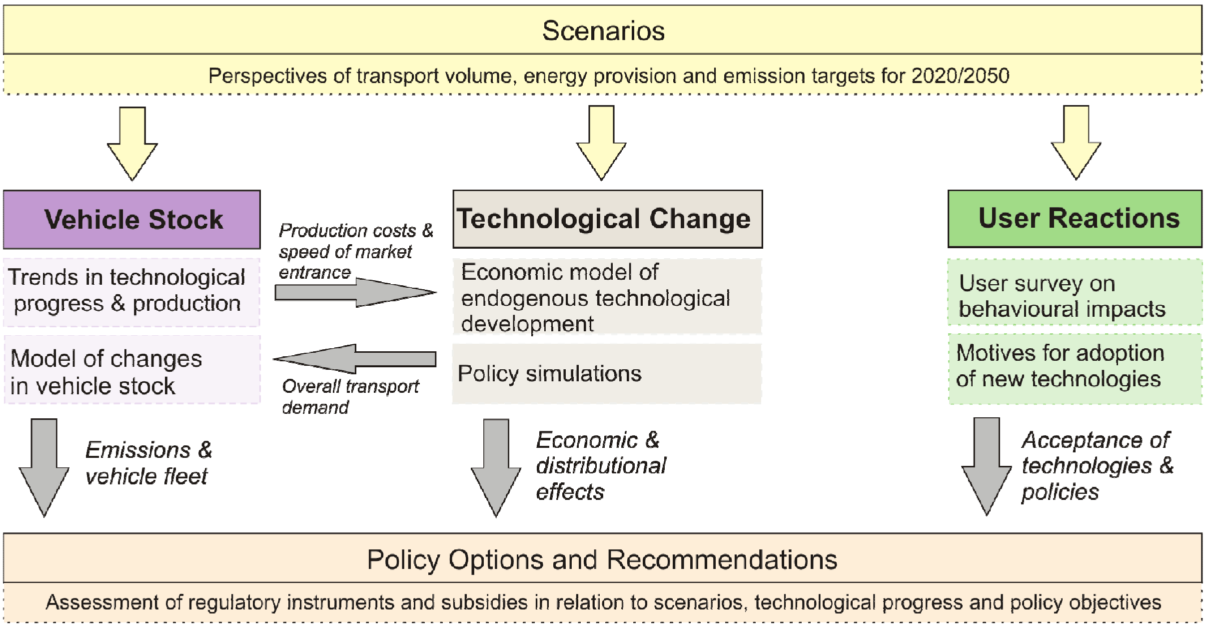

Figure 1: STEP research design

Besides a business-as-usual scenario on forecasts of vehicle technology development up to 2050 [REF], seven policy scenarios were analyzed that foster the progress of alternative passenger transport technologies in order to reduce greenhouse gas emissions via technological switch:

- Phase out of ICE and subsidy in R&D [PhaseICE_RD], introducing regulatory standards on car emission levels and subsidies for research & development;
- Increase in fuel tax and subsidy in R&D [FuelT_RD], increasing fossil fuel prices;
- Road pricing and subsidy in R&D [RPr_RD], taxing variable transport costs differentiated by technology;
- Road pricing and enhancement of public transport [RPr_PT], as above plus subsidizing public transport prices;
- Acquisition tax [AqT], differentiating the tax rate at car purchase by the carbon content of each technology;
- Acquisition tax and enhancement of public transport [AqT_PT], as above plus subsidizing public transport prices;
- Output subsidy on FCEV [OutFCEV_FT], decreasing the purchase price of fuel cell electric vehicles.

The stringency of the policy scenarios in terms of tax rates, degree of price subsidies, etc. followed the rationale of feasible policies which connect to current initiatives at the national and EU level and which are likely to be accepted by the public. Acknowledging that it is debatable which exact degree of stringency is within or beyond public acceptance, we aimed thereby for a realistic perspective in the scenario results. As a side effect of introducing 'realistic' scenarios, we observe only moderate impacts. However, drastic changes within scenarios would put the validity and sensitivity of the modeling framework into question.

Core results and policy recommendations

Judging from VeTCoM technological learning curves, EVs are cost competitive to other propulsion technologies after a worldwide introduction of electric mobility with a correspondent rise in global production figures. The most relevant cost components are the electric drive train and the battery; thus, high learning rates in these sectors are crucial. PHEVs might serve as a transitional technology due to their technological requirements similar to ICEs. In contrast, FCEVs show little chance in competition with the electric drive train within the next decades, due to their high proportion of material cost.

Generally speaking, the earlier the entrance of alternative propulsion systems in the mass market and thus the more technological change is accelerated by faster learning rates, the higher is the payoff in overall carbon emission reduction, as cumulated emissions can be avoided from early on.

EU carbon emission reduction targets call for a reduction by -16% within non-ETS sectors such as the transport sector from 1990-2020, and -80% from 1990-2050. The business-as-usual scenario REF does not achieve these targets for the passenger car sector, as we predict a change of CO2 emissions from 1995[1] to 2020 of +10% and from 1995 to 2050 of -42%. Therefore, the problem of carbon emissions in transport will not be solved on its own – the effect of autonomous technological change for passenger cars alone is too weak to fulfill policy targets.

PhaseICE_RD as the most stringent scenario achieves a change in CO2 emissions from 1995 to 2020 of +1% and from 1995 to 2050 of -46%, thereby failing to fulfill EU emission targets, too. Nevertheless, PhaseICE_RD curbs the short-term growth in emissions until 2020. Consider that the EU targets refer to a certain level of emission at a certain date: When instead accumulating the emission reductions achieved in each year leading up to the EU target date, the policy scenarios achieve an emission reduction of up to –9% in PhaseICE_RD until 2050 compared to REF. If PhaseICE_RD is complemented by additional policies towards environmentally friendly passenger transport, the EU targets might be within reach. All other policy scenarios are farther off the desired emission reduction, thus making achieving the EU targets even less probable.

Emissions conforming to the EU targets seem feasible, if green electricity produced with very low carbon impacts would be available in Austria from 2005-2050: REF remains at +10% until 2020, because electrical propulsion technologies hardly enter the market by then, but REF reaches –73% by 2050. PhaseICE_RD achieves –10% in CO2 emissions from 1995 to 2020 and –80% from 1995 to 2050. Under the green electricity assumption, the other policy scenarios reach at least –76% by 2050 (except in OutFCEV_FT), thus underlining the necessity for profound changes in energy production.

[1] STEP models were calibrated to the starting year of 1995. However, modeling technological change impacts relative to the base year of 1990 would only exacerbate the discrepancy to EU targets.

Table 1: result overview – energy use and CO2 emissions for the year 2020 and 2050

passenger car energy use and CO_2 emissions [TWh, 1000t, %]												
	TWh in 2020			**TWh in 2050**			**CO_2 in 2020**			**CO_2 in 2050**		
	TWh	ΔTWh	%	TWh	ΔTWh	%	1000t	Δ1000t	%	1000t	Δ1000t	%
REF 1995	35			35			9394			9394		
REF	41	6	17%	20	-16	-44%	10298	904	10%	5489	-3905	-42%
FuelT_RD	41	6	17%	17	-18	-51%	10287	893	10%	4914	-4480	-48%
PhaseICE_RD	36	1	4%	18	-17	-49%	9449	55	1%	5113	-4281	-46%
OutFCEV_FT	41	6	17%	22	-13	-38%	10298	903	10%	4762	-4632	-49%
AqT	40	4	13%	18	-17	-48%	9967	573	6%	5201	-4193	-45%
AqT_PT	40	4	13%	18	-17	-48%	9964	570	6%	5198	-4196	-45%
RPr_PT	41	6	17%	19	-16	-46%	10295	901	10%	5360	-4034	-43%
RPr_RD	41	6	17%	19	-16	-46%	10300	906	10%	5363	-4031	-43%

Overall, differences of the policy scenarios in 2050 compared to the reference scenario REF are moderate. We find that all policy scenarios are effective in pushing ICE faster out of the market than REF, fastest in PhaseICE_RD, followed by AqT. FuelT and RPr are similarly effective on ICE. PHEV have a clear status as transitional technology throughout, paving the way for EV.

EV adoption does not vary much between scenarios, but is fastest in FuelT: Since EVs do not rely on fossil fuels, the technology is able to overcome the initial cost-disadvantage to PHEVs much faster.

FCEVs only enter the market by extensive subsidizing in OutFCEV_FT. Without policy support, FCEVs would not become cost competitive to other propulsion technologies within the timeframe to 2050.

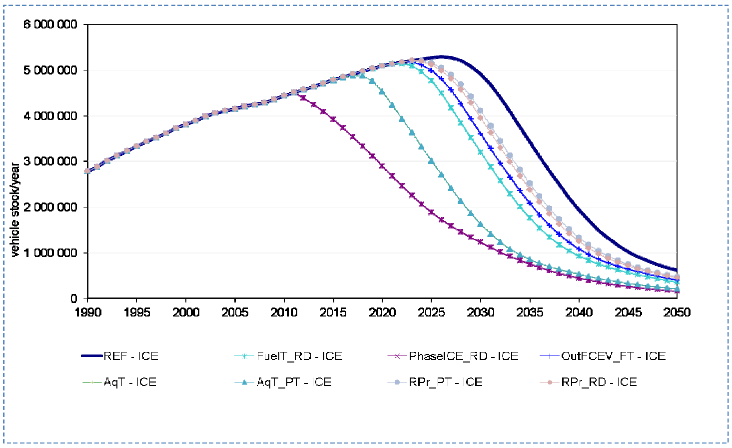

Figure 1: ICE – car vehicle stock for 1990 – 2050

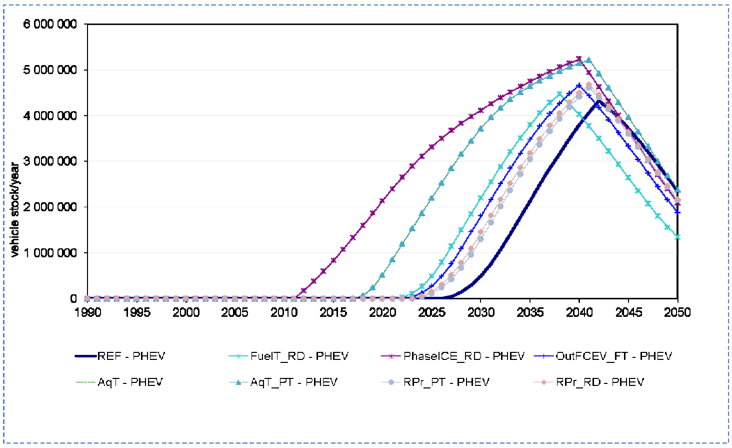

Figure 2: PHEV – car vehicle stock for 1990 – 2050

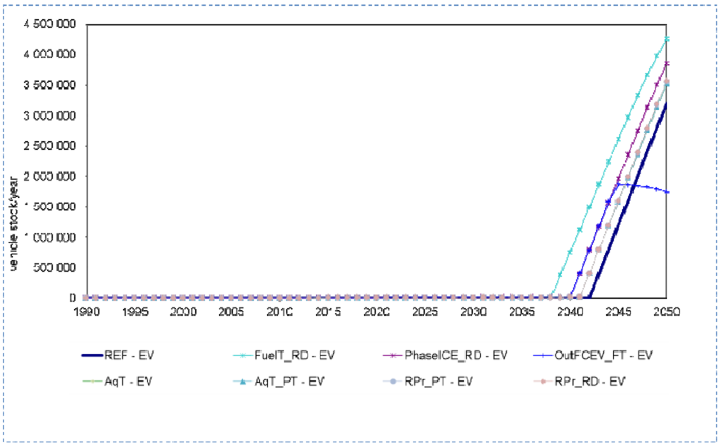

Figure 3: EV– car vehicle stock for 1990 – 2050

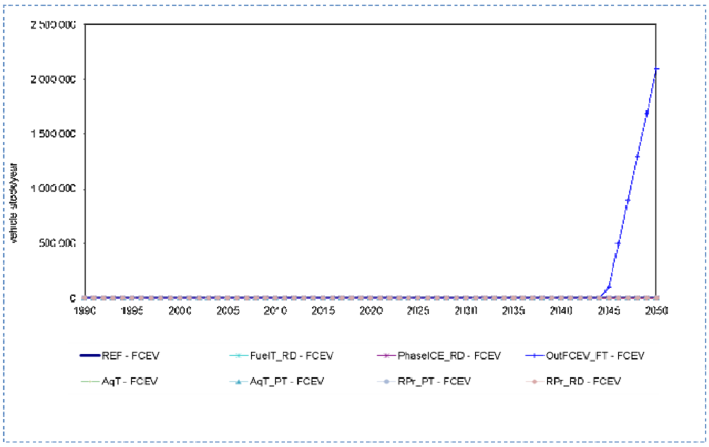

Figure 4: FCEV – car vehicle stock for 1990 – 2050

PhaseICE_RD amounts to a strict regulatory policy which forces consumers to a switch in technology. This scenario is most effective in terms of emission reductions, but implies strong increases in prices. Households have to spend more for mobility costs in the first decade, until alternative technologies to ICE enter the market. As a massive command and control approach, this scenario needs strong support by public stakeholders. In this regard, PhaseICE_RD can be compared to the exit from nuclear energy in the German energy transition ('Energiewende').

Similarly, AqT and FuelT_RD lead to substantial immediate effects on ICE vehicle stock in the first years, but limit household consumption. This raises concerns regarding distributional effects, and by extension effects on intergenerational equity. Population cohorts living during the first stage of policy implementation will be strongly negatively affected, but they may not profit from the positive effects of the policy some decades later, when they no longer participate actively in the transport system. These adverse impacts could be alleviated by gradual implementation, thereby distributing the burden of the policy over a longer time and a broader population cohort.

Both road pricing scenarios RPr_RD and RPr_PT achieve similar effects regarding emissions and welfare/distributional effects. Therefore, a decision between these two scenarios should be driven by other policy goals such as administrational feasibility / transaction costs, public acceptance, or potential interlinkages with other policy measures.

Finally, OutFCEV_FT's high subsidy on the retail price goes at the expense of public transfers to households, thereby reducing household's disposable income. We do not recommend this scenario, since the considerable level of subsidy is disproportional in relation to the achieved impact. We observe that FCEVs need an excessively high subsidy in order to achieve any market entrance by 2050 at all. We expect that an eventual effect of this scenario will not develop earlier than within a time horizon by 2080.

Overall, we find marginal differences whether scenarios target fixed or variable costs of transport, e.g. purchase price or fuel costs. Thus, policymakers could base their decision on a certain avenue of intervention on criteria such as transaction costs for administration, expected public acceptance, or consumer preferences in discounting costs (such as disregarding long-term variable costs as long as initial fixed costs are low).

Results from the survey show that early adopters are predominantly comprised of persons aged 60 years or older who mainly use the e-bike for leisure purposes. Although a quarter of commuting and shopping trips, and a third of leisure trips are undertaken with the e-bike, the early adopters mostly switch from environmentally friendly travel modes (public transport, conventional bicycles) to the e-bike instead of substituting the car. Early adopters typically hold pro-environmental and technophile attitudes. Within the elderly user segment, it seems that the main effect of providing subsidies was in improving opportunities for social participation rather than decreasing carbon emissions from passenger transport. Most households had not possessed an e-vehicle before receiving the subsidy, thus the subsidies did indeed increase technology adoption. However, the number of fossil-fuel powered cars and motorbikes remained constant in most households despite the purchase of the e-vehicle.

E-bike use is most driven by perceived usefulness, which in turn depends on an easy use, appropriate infrastructure and user's norms and attitudes towards environment and physical health. Comparison by trip purpose shows that a supportive social environment and personal ecological norms influence e-bike use on work and shopping trips, whereas leisure use of e-bikes is driven by attitudes towards physical activity. Comparison by age groups underlines that older e-bike users are more dependent on practical usefulness of the technology and facilitating road infrastructure.

In a complementing strand of research, we outlined four strategic scenarios to describe possible futures for electric vehicles. The first scenario, obviously, has to evaluate the possibility that also the present effort will fail to implant EVs in the market, as this has historically happened twice before (at around the 1920s and in the 1990s). The second scenario describes a scenery of utmost confusion where each country tries to succeed with its own norms and approaches; a situation which is depressingly similar to the present situation. The third scenario uses the market introduction of LED screens as a blueprint, which saw a very long struggle with very slow progress but ultimate success. This is the pattern we see at present with sustained painful efforts to develop more efficient batteries, marred by a long history of setbacks, e.g. laptops in the 1990s with batteries that suddenly burst into flames and burnt their users or the problems of Boeing's new Dreamliner aircraft with its lithium-ion batteries. However, now for two decades batteries have seen a slow but steady progress of an increase in battery capacity at constant costs by 7.7% per year. Ultimately, this could allow progress but not before the 2030s at the earliest; more likely at around 2050 as foreseen by a committee of the U.S National Academy of Science. The fourth scenario has to contemplate the remote possibility that against all odds "the Black Swan" (Khosla) is found, i.e. the sudden success of EVs out of the blue. This is the most difficult but simultaneously highly important scenario because the past economic development is also characterized by so-called disruptive change where millions lose their jobs, old regions decline painfully and new regions, new countries and new industries emerge.

From the above analyses by VeTCoM, CGE and NEMO, we expected the market entrance of EVs at competitive prices no earlier than 2040. However, VeTCoM learning curves reflect state of practice in the mainstream industry in 2012.

Based on an analysis of strategic scenarios depicting possible futures of EV, to our surprise it turned out that the world is experiencing a Black-Swan situation, where a successful technology emerges unexpectedly out of the blue. Thus we devoted a case study to the company and the vehicle in question, Tesla Motor's Model S sedan, an expensive luxury car that does not at all fit established patterns of EVs. An EV has to be expensive, but also small, heavy, cramped and a nightmare even for devoted environmentalists. We show the massive technological breakthrough regarding battery capacity in EV in the Tesla Model S electric sedan car that was recently introduced on the market. Given practicability in long-term use and transfer of this technology in non-luxury car market segments, the Model S might signify a much faster, or even impending, entry of EV in the mass market.

4 Conclusion and outlook

As described in the section on core results and policy recommendations above, a swift entrance of alternative propulsion systems in the mass market is crucial so to decrease overall vehicle costs rapidly by economics of scale, and to avoid cumulative carbon emissions from early on. In order to achieve EU emission targets for 2020, the most stringent policy scenario (phase out of fossil-fuel powered cars by implementing car emission standards) needs to be complemented by additional policies towards environmentally friendly passenger transport or green electricity production. Autonomous technological change for passenger cars alone without strong policy action is too weak to fulfill policy targets. Subsidies to private households for the purchase of an electric vehicle are not an efficient measure, since impacts on less carbon intensive mobility behavior are small compared to the amount of subsidies paid out.

Relevance and transfer of project results to practice

STEP targets an increasingly important question in Austria, namely the future of alternative vehicle propulsion technologies. STEP supports the development of policies for promoting technological change, and thus it contributes to the sustainability of the implementation of a new transport system in Austria. The results shall assist an informed decision-making by stakeholders through an increased understanding of policies and their options and restrictions as well as their ecological and economic implications.

Transport is a sector for which it is difficult to develop appropriate policies. The project results therefore have a high value for policymakers at the regional and national level as well as for producers of low carbon transport technologies. In particular the project can accelerate the early design and implementation of appropriate polices. Regarding target groups who might transfer the project results to real-world application, see section 4. All funding agencies who participated in the conduction of the survey received factsheets detailing target group specific market uptake, mobility impacts and leverage of the subsidies they paid out within their jurisdiction. To the knowledge of the project team, this tailored information instigated revisions of subsidy guidelines in several cases.

STEP's methodology is a structured approach to pre-test climate policies intending to foster different technologies and to evaluate whether they are sufficient to achieve certain policy targets. Furthermore, our framework supports the integration between socio-economic and technical spheres. The findings can help to shape future implementation and innovation processes triggered by decision-makers towards higher efficiency.

The economic/market potential of the STEP project lies in informing stakeholders, how technological change in vehicle propulsion technologies can be expected to develop and how it can be influenced by public policy. Relevant stakeholders encompass predominantly public administration and politicians at provincial and national level, but car companies as well as environmental or industrial advocacy groups were found to consider the results of high interest as well.

Potentials for future research

We recommend future research on the one hand on the interrelation between technological change and general framework conditions of the transport system (e.g., system boundaries), on the other hand on collecting empirical data on price elasticities by monitoring the market development as soon as a certain technology breaks through to the mass market.

The case study on the recently introduced Tesla Model S shows an upcoming disruptive technological change due to reduction in battery costs, enabling a much earlier breakthrough of EV technology. The consequences of this innovation might be extensive, e.g. forcing car manufacturers to radically reorganize their production chains, spreading out to supplier businesses and the labor market. This recent technological development by no means makes the above analyses of VeTCoM, CGE and NEMO invalid. Provided that the Tesla production figures can be transferred to the entire car sector, revised learning rates can be entered in the well-established STEP modeling framework to recalculate scenarios, profiting from the detailed analysis of policy impacts on car fleet, emissions and non-transport economic sectors.

By its very design, STEP's scope is limited to technological change in vehicle propulsion. However, the overarching issue of moving towards less carbon intensive motorized passenger transport by means of technology is connected to additional, bigger questions: Is it commendable if households possess cleaner cars on the one hand, while the increase of household vehicle stock continues, disregarding all other negative externalities of car traffic? Further studies could relate alternative vehicle propulsion technologies to ecological travel mode choice, soft measures for awareness building, or spatial planning. The economic growth and demographic change implemented in the CGE model lead to growth in transport volume, but will system boundaries emerge, preventing future growth? We refrained from strict system boundaries in our modeling framework as it is unclear how a boundary could be defined (e.g., in terms of depleted resources, collapse of the transport system by overcrowded roads, etc.) and when it will become effective. However, studies on temporal dynamics in resource constraints would surely improve our modeling results.

On a less general level, we find ample leverage to extensions of our research, partly by following up on modeling assumptions or simplifications we made:

- STEP focused on direct emissions from passenger transport. Detailed life cycle analyses could look into rebound effects on overall emissions as households redistribute their consumption from mobility to other goods, or as diverse industrial sectors and their intermediary consumption are affected by the policies proposed in the scenarios.
- FCEVs require additional infrastructure such as hydrogen production facilities and adapted fueling stations which is not explicitly represented in the STEP analyses. However, building this infrastructure might trigger cross-sectoral effects or time lags in the market entrance of FCEVs.
- STEP pictured the consumption of individual passenger transport as possession of a vehicle by a household. However, a higher proportion of car-sharing and other mobility services relying on shared use could severely impact the market position of the respective vehicle technologies. In a similar vein, STEP assumed trends regarding the number of passengers per vehicle, and regarding car travel performance in annual kilometers driven per household. However, these numbers might be subject to change through policy intervention, shifts in lifestyle preferences or other societal changes. In particular, self-driving vehicles, with their impending market introduction in 2013/2014 in several U.S. Federal States, can substantially change present patterns of car ownership. Here we are at an early phase of this development. For lack of reliable trend data, STEP did not elaborate on these aspects.
- We find relatively sudden changes in market shares within a period of few years as soon as a technology achieves a competitive price on the mass market. Modeling the turnover of the entire vehicle stock in NEMO smoothed these short-term peaks, though we still ignored early adopter customer segments who buy a technology already at non-competitive prices. A more detailed analysis of the diffusion process could differentiate between customer segments with varying price expectations and affinity to specific technologies, ideally determining respective price elasticities empirically. Originally, we planned to provide such data from our survey of e-vehicle users, but the net sample contained just 5 e-car users, concordant to the currently low market penetration of e-cars in the overall Austrian passenger car stock.
- Monitoring studies as soon as a certain technology breaks through to the mass market could provide much-needed empirical data on technological change. Observing actual changes in purchasing behavior and transport consumption during the process of an alternative technology entering the market could yield interesting insights: Not just price elasticities of vehicle technologies and customer segments could be established, but also elasticities between car and public transport, or impacts on the used-car market, as it remains open how second-hand PHEVs, EVs and FCEVs sell as used cars, especially concerning durability and loss in capacity of resale batteries. Monitoring studies could also prove valuable as soon as emissions stemming from electricity production are improved, for example by a massive rollout of photovoltaics.

As stated above as a project highlight, the sound methodological framework will allow for reproducibility and applicability to other contexts, e.g. by revising learning rates due to recent market developments as with the Tesla Model S, by including additional propulsion technologies, or by transfer of the modeling framework to other technologies. We will continue to observe the emerging technology of the Tesla Model S, as it provides an interesting showcase how an unexpected radical innovation diffuses into the mass market, potentially rearranging the entire transport system.

C) Project details

5 Method

The STEP modeling framework links detailed learning curves from the VeTCoM model, technological change and market entrance from the CGE model, and impacts on car fleet and emissions from the NEMO model. This framework is innovative in that it brings together complementary modeling approaches which compensate the weak points of stand-alone models: The CGE model depends on reliable estimates for learning rates and could not derive valid calculations of emissions on its own. The NEMO model profits from the endogenous estimation of car sales figures.

See the research design in section 3 above, and the respective manuscripts and technical reports (section 7 below).

6 Work and time plan

	2011												2012												2013	
	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
WP1	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
WP2													■	■	■	■	■	■	■							
WP3	■	■	■	■	■	■	■	■	■	■					■	■	■	■	■	■	■	■				
WP4	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
WP5				■	■	■	■	■	■	■	■	■					■	■	■							
WP6																					■	■	■	■	■	■

WP1: Project management
WP2: Scenarios
WP3: Vehicle stock
WP4: Technological change
WP5: User reactions
WP6: Policy options and recommendations

7 Publications and dissemination

Authors	Title	Publication channel
Manuscripts		
Veronika Kulmer	Promoting alternative, environmentally friendly passenger transport technologies: Directed technological change in a bottom-up/top-down CGE model	published as Graz Economics Papers, 2013-02, http://econpapers.repec.org/paper/grzwpaper to be submitted to Transport Policy
Veronika Kulmer, Karl Steininger	Technological change and passenger transport technology details in a CGE modelling framework	under review for publication as Wegener Center Report
Michael Schwingshackl	Vehicle Technology and Cost Model – VeTCoM	under review for publication in IVT Mitteilungen
Michael Schwingshackl, Stefan Hausberger, Raphael Luz, Martin Rexeis, Martin Dippold	Impacts of policy scenarios on vehicle stock and emissions: Linking CGE model and Network Emission Modell (NEMO)	under review for publication in IVT Mitteilungen to be submitted to the Transport & Air Pollution Congress 2014
Sebastian Seebauer, Angelika Wolf	Technology adoption of electric bicycles: A survey among early adopters	to be submitted to Transportation Research D Transport and Environment
Wolf Grossmann, Sebastian Seebauer, Karl Steininger	Electric Vehicles: How can they succeed? - Analysis, Scenarios & Recommendations	to be submitted to Transportation Research D Transport and Environment
Technical reports on methodological details and specific aspects		
Sabine Puffer	Policy recommendations: Fostering alternative vehicles in Austria	STEP Technical Report
Sebastian Seebauer, Angelika Wolf	Survey of E-vehicle Users. Methodology and Data Collection	STEP Technical Report
Angelika Wolf	Qualitative Interviews zum Thema Elektromobilität	STEP Technical Report

Fact sheets on the user survey (in German language) detail results for subsamples from the cities of Klagenfurt, Villach, Linz, and Vienna, and the provinces of Styria, Lower Austria, Carinthia, and Burgenland, as well as results for the overall sample in respect to the whole Austrian population.

Authors	Title	Publication channel
Conference presentations		
Martin Dippold, Martin Rexeis, Stefan Hausberger	NEMO – A Universal and Flexible Model for Assessment of Emissions on Road Networks	19th International Conference on Transport and Air Pollution, Thessaloniki, November 26-27 2012
Veronika Kulmer	Directed Technological Change in a Bottom-Up/Top-Down CGE model	Conference of Economic Modeling, Seville, Spain, July 4-6 2012
Michael Schwingshackl	Learning effects: When become electric cars cheap – a model based analyses	Kuhmo Nectar Conference, Berlin, June 21-22 2012
Veronika Kulmer	Promoting alternative, environmentally friendly passenger transport technologies: Directed technological change in a bottom-up/top-down CGE model	Conference of the European Association of Resource and Environmental Economists, Toulouse, France, June 26-29 2013
Karl Steininger, Wolf Grossmann, Veronika Kulmer, Sabine Puffer, Sebastian Seebauer, Angelika Wolf, Stefan Hausberger, Martin Dippold, Martin Rexeis, Michael Schwingshackl, Michael Zellinger	Instrumente für die Markteinführung von CO2-armen Antriebstechnologien für Fahrzeuge	Austrian Climate Day, April 4-5 2013
Sebastian Seebauer, Angelika Wolf	Technology adoption of electric bicycles: A survey among early adopters	Conference on Environmental Psychology, Magdeburg, September 22-25, 2013
Doctoral and Master's theses		
Veronika Kulmer	Policy Analysis in a Computable General Equilibrium Framework: Case Studies on Trade and Transport Policy	Doctoral Dissertation at the Department of Economics, University of Graz, submitted in February 2013
Angelika Wolf	Climate friendly consumer behavior	Doctoral Dissertation at the Department for Sociology, University of Graz, to be submitted in October 2013
Sabine Puffer	Political measures to accelerate the diffusion process of alternative propulsion vehicles: Scenarios for Austria	Master's Thesis at the Department of Economics, University of Graz, submitted in April 2013
Eva Kouba	Soziale Diffusion von umweltrelevanten Einstellungen am Beispiel von Elektromobilität	Master's Thesis at the Department for Sociology, University of Graz, submitted in July 2013

In addition, bachelor theses by Sabine Glettler and Matthias Schils, supervised by Sebastian Seebauer, analyzed survey data from participants in the e-car trial program "Lebensland Kärnten" of the provincial government of Carinthia. Veronika Kulmer supervised bachelor theses of Barbara Stocker on policy instruments and options for the promotion of electric vehicles in Austria, and of Philipp Kulmer on the role of electric bikes in rural regions.

Diese Projektbeschreibung wurde von der Fördernehmerin/dem Fördernehmer erstellt. Für die Richtigkeit, Vollständigkeit und Aktualität der Inhalte übernimmt der Klima- und Energiefonds keine Haftung.