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Author(s):
Späth, Leonhard; Tröndle, Tim; Patt, Anthony

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Potential costs and benefits of a right-to-charge policy: an example for Switzerland

Leonhard Späth[a,*], Tim Tröndle[a], and Anthony Patt[a]

[a] Swiss Federal Institute for Technology Zürich (ETH Zürich), Department of Environmental Systems Science (D-USYS), Universitätstrasse 16 (CHN K76.2), 8092 Zürich, Switzerland.

* E-mail: leonhard.spaeth@usys.ethz.ch, corresponding author.

Abstract

Electric vehicles (EVs) are essential to decarbonize individual mobility and their adoption is highly dependent on the possibility of charging at home. However, tenants in multi-family apartment buildings face legal and financial barriers to the installation of home-charging. Through this study for Switzerland, we make the case of the economic benefits of a policy overcoming these barriers. Through an extrapolation of the EV diffusions towards 2035, we show that the benefits of switching towards EVs are overwhelming positive for its users and for society in general. The acceleration of EV adoption through a right-to-charge policy can potentially benefit the Swiss population by about 12 billion USD, corresponding to about 1.5 percent of GDP. Failing to implement an easy access to home charging-infrastructure in a timely manner will results in a considerable loss for the Swiss economy, eventually at the costs of citizens and the climate.

Keywords: Electric mobility, sustainability transition, right-to-charge, cost benefit analysis, Switzerland

1 Introduction

Electric vehicles (EVs) are seen by many analysts as an essential technology in the push to end CO_2 emissions and avert potentially catastrophic climate change, while also leading to major reductions in local air pollution (Jaramillo et al. 2022). They are rapidly gaining market share; while to a large extent this has been due to policies that have supported their early diffusion, more recently they have benefited from falling costs for battery production (Liu et al. 2021; Goetzel and Hasanuzzaman 2022). Their overall environmental performance appears to represent a great improvement on vehicles with internal combustion engines (ICEVs), making them viewed positively from a policy-making perspective (Baars et al. 2021; Sacchi et al. 2022). Several jurisdictions have enacted policies to achieve close to 100% market share at various times in the future, as a result of light vehicle emissions standards falling to zero. In Norway this will happen in 2025, in the UK in 2030, and in California and the EU in 2035.

Nevertheless, researchers have identified a number of factors that can slow their diffusion. Two major factors in the past were their relative high price, and their limited range. Both of these factors appear to be vanishing, as the total cost of ownership for EVs has fallen to below that of comparable ICEVs (Liu et al. 2021), and as the size of EV battery packs has increased (Melliger et al. 2018). The availability of public charging, such as along highways, has also been seen in the past as a major problem, and yet this situation too has changed, with ample public charging now available in those markets where EV diffusion is strong; market forces have led to the provision of needed infrastructure (LaMonaca and Ryan 2022).

A final barrier is access to private charging infrastructure, and in particular charging at the parking space that the individual car owner uses to park her vehicle overnight. Research has shown that the ability to leave home with a fully-charged battery is essential for range issues to be resolved (Melliger et al. 2018). In some cases, car purchasers have the legal right to install a charger in such spaces, such as with the owners of single-family houses with their own driveway or garage. For many, however, this is not the case, as with car owners who live in apartment buildings, and park their car either in an underground parking garage, or on the street. Research has shown that such car owners are up to 50% less likely to consider purchasing an EV as their next vehicle, compared to those who can easily install a charger at home (Patt et al. 2019). This can result in a slow-down in EV adoption, like it is starting to happen in Switzerland (Etienne 2023), and potentially elsewhere in other countries.

1.1 Adoption of EVs when charging at home is available

As background for this current study, we examined the issue of private charging infrastructure in greater detail, using a mixed-methods approach in Switzerland. In July 2020, we conducted an online survey experiment of Swiss car owners, with 438 responses from those living in apartment buildings for whom private charging availability is problematic (Shuang 2020). We asked them to indicate their likelihood of purchasing an EV as their next car, assuming a number of different possible policy scenarios. Those scenarios included (a) good availability of public charging infrastructure within 2 km of their residence, (b) good availability of public charging close to home and at their place of work, (c) good availability of public charging close to home and at shopping malls and other non-work destinations, and (d) access to a charger in the parking spot where they park their car overnight. The results indicated no significant differences between the first three groups, and across these three groups fewer than 50% of respondents indicated they were somewhat likely to purchase an EV as their next car. In the case of the final scenario – availability of private charging, over 75% indicated that they were somewhat likely to purchase an EV. These results were similar to baseline results in Patt et al. (2019), suggesting that access to private charging is the main determinant of the willingness to purchase an EV, whereas improved availability of public charging makes very little difference.

As part of the same study, we also conducted 13 expert interviews in Switzerland, with professionals involved in the business of EV sales and charging installation. The interview results suggested that the market is not rushing to make private charging available in apartment buildings, given the current lack of legal clarity about who will bear the cost of expensive building retrofits required before chargers can be installed at individual parking spaces.

One solution to this lack of private charging, providing clarity with respect to initial investment costs, is a so called right-to-charge law. At the most basic level, such a law gives building tenants who use the building's parking garage the legal right to access a charging station at the parking space they ordinarily use. Different versions of the law contain different cost allocations. In Germany, such a law gives tenants a legal right (WeMoG 2020), and yet leaves open who would pay for the needed building retrofits. In Norway, the government provides for the cost of such retrofits with a government subsidy program (Elbil 2023). We consider a meaningful right-to-charge law being one that creates a fair allocation of costs among relevant parties: individual car owners would bear some or all of the costs of installing the charging station at their space, while the costs of building retrofits would be born either by the public hand (as in Norway), or by all building tenants using the parking garage.

1.2 Economics of right-to-charge policy

Before appraising the economic case for a right-to-charge law, as we do in this paper, it is worthwhile to consider whether there is a case for any public policy to intervene in the EV market development. It appears that there is, because of the existence of a market failure. It is a core finding of neo-classical economics that freely functioning markets, in the absence of any special problems, allocate labour and capital to the production of different goods and services in a manner that maximises overall societal economic welfare. The special problems that can arise, leading free markets to fail to do so, are known as market failures (Bromley 1990). In the presence of a market failure, free markets will fail to allocate resources efficiently, a condition that justifies policymakers' intervention (Markovits 1975).

Market failure can take a number of different forms, with their form determining the ideal policy intervention to correct them. For example, the presence of a monopoly or cartel can lead to inefficient supply restrictions; a favoured response comes in the form of anti-trust legislation, which breaks up monopolies and prohibits the type of collusive behaviour underlying cartels (Block and Jankovic 2022). In the area of the environment, the most frequently observed market failure derives from the presence of external costs; in these cases, the economically efficient solution is to impose a pollution tax or fee that forces polluters to bear those costs (Portney and Stavins 2000). Hence, depending on the nature of the market failure, an effective and efficient response can either be of a regulatory or a financial nature.

The market failure that we observe in the case of EVs is one that misallocates resources as a result of a coordination problem (Friedman 1994). Coordination problems exist when the economic actions of one actor affect the costs and benefits of others' economic actions (Sákovics and Steiner 2012). A common example is when one economic actor – or a collection of economic actors – is responsible for investing in an infrastructure network, and the presence of that network affects the costs and benefits of others in society with respect to investments into products that depend on the presence of the network. Society as a whole would benefit if the network were in place, and yet those investing in the network might have different incentives, and fail to do so. Researchers have proposed various solutions to coordination problems, such as these with networks, and one common approach is for a central decision-maker to mandate a responsible party to undertake the network investment, whether that responsible party is a private entity or the government itself (Hamman et al. 2007). This justification arises frequently to support laws around public infrastructure such as roadways

(Winston 1991). This is exactly the approach that a right-to-charge law takes, in terms of mandating those responsible for infrastructure networks (e.g. building wiring to which EV chargers would connect) to make the investments needed for an efficient outcome for society more generally.

1.3 ICEV lock-in for households in rented or co-propriety apartments

The following scenario – which we have observed anecdotally on many occasions – illustrates the nature of the coordination problem. Imagine that 20 families own their own apartments in a large building, and collectively make decisions, through an owners' association, with respect to building upgrades. All of them have one parking space allocated to them in the building's parking garage, and currently all of them own one ICEV. One family (the Smiths) decide that they want to purchase an EV, and are willing to install at their own cost (e.g. $1,000) a charger for the space where that EV will be parked. For this to happen, however, the building's wiring needs to be extended to their space. The Smiths request the building owners' association to do this. The owners' association quickly determines that extending the wiring to the Smith's parking space would cost $10,000, while extending wiring to all 20 spaces, and installing a load management system, would cost $30,000, or $1,500 per space. The Smiths ask for this latter solution, deciding that purchasing an EV is worth the additional cost of $1,000 for their own charger plus $1,500 for the needed building renovations. However, only a few of the other owners have thought of purchasing an EV for themselves in the foreseeable future, and a majority of the owners are unwilling to pay $1,500 for a renovation that they do not see as valuable to themselves. The Smiths decide not to purchase an EV, and opt for a new ICEV instead. Several months later, the issue comes up when another family considers purchasing an EV. They make a similar request, with the same result. Indeed, the Smiths, having just purchased a new ICEV and not foreseeing a new EV for many years, are among those voting against the building renovation. The pattern repeats itself over and over again. Indeed, eventually, all 20 building tenants make a request, as some point, for the wiring renovation. None of the requests are approved, because they were made in an uncoordinated pattern, rather than all of them at once. If all of them had made the request at the same time, the outcome would have been different, the renovations would have been made, and EV diffusion would have been faster.

A right-to-charge law, particularly one that creates a fair allocation of the initial investment costs, would avoid this problem. In this case, the Smiths would have the right to demand the building renovations needed to wire their parking space, and would not have to pay those cost entirely themselves. At the building owners' meeting, several other families indicate that they too will be asking for charging in the coming months, and so it is quickly determined that the cost-effective solution is the full renovation option. The costs for this are either paid by the state, or by all of the building occupants. Once the renovation has happened, each of the other families ends up purchasing an EV as their next vehicle.

A right-to-charge clearly makes sense as a means to accelerate EV diffusion. A critical question, however, is whether it also brings economic benefits to the actors involved. These actors include the car owners, who on account of the right-to-charge are more likely to purchase an EV. The actors could also include the local community which might decide to pay for the cost of needed retrofits; they are affected by differences in air and noise pollution generated by EVs and ICEVs. Finally, one could consider the relevant actors to be the entire planet; through CO_2 emissions and climate change, they are affected by the EV purchasing decision. Ultimately whether a right-to-charge law represents an important correction of a market failure is determined by whether the accelerated shift to EVs, which the law would produce, brings net economic benefits. In the remainder of this paper, we assess the costs and benefits at these three levels.

2 Methods

We evaluate the net costs or benefits of the accelerated diffusion of EVs, which a right-to-charge law would promote. In doing so, we consider three categories: (1) the direct costs/benefits to the owner of vehicles, (2) the indirect local costs/benefits of the reduced air pollution, and (3) the indirect global costs/benefits associated with reduced CO_2 emissions of EVs relative to ICEVs. In all three cases, our focus is on the difference in costs between ICEVs and EVs, rather than the absolute value of those costs.

We carry out our calculations for Switzerland, where we only consider new car registrations from 2023 towards 100% EV new registrations by 2035. Switzerland makes an appropriate case study, as it has so far seen a relatively rapid diffusion of EVs, and yet is also a country with a relatively low rate of single-family home ownership. The 2035 date is a function of the fact that the European Union (EU) has established a zero emissions standard for new light vehicles that would go into effect that year (EU 2023). As Switzerland's vehicle regulation is integrated with that of the EU, this means that it is unlikely that new ICEVs will be available to Swiss car buyers starting in 2035; in that year, the new car market would achieve 100% market share of EVs. Under an accelerated diffusion pattern, the new market could begin to approach 100% EVs several years before the 2035 deadline.

2.1 Direct costs/benefits to the car owner

For the direct costs/benefits to the car owner, we assume a set of substantial core differences between EVs and ICEVs. These are shown in Table 1, and begin with the pre-tax cost of the car itself. In this case we project the additional cost of EVs over ICEVs, by category (Goetzel and Hasanuzzaman 2022); to do the latter, we assume for the Swiss market, based on current average vehicle price statistics, that the market is made up of 25% economy cars, 25% mid-cost cars, and 50% higher performance or cost cars. Other cost differences accrue over the lifetime of the vehicle, for which we use a fixed value of 15 years, representing the average vehicle lifetime in Switzerland (Hels et al. 2021), with a fixed distance travelled per year at 15,000 km to correspond to the current Swiss average (BFS 2021a; TCS 2023). We discount these to the year of vehicle purchase using a discount rate of 3% (see SNB 2023). One factor is maintenance costs, for which recent literature suggests is substantially less in the case of EVs (Liu et al. 2021). There is evidence that EV tires need more frequent replacement, due to added vehicle weight (Beddows and Harrison 2021). To be conservative, we hence assume that EVs require 25% more frequent tyre replacement (see Table 1). There is anecdotal evidence that EVs have a higher resale value in the short term (AGVS 2021), but to be conservative we assume no difference in this respect. We assume energy use for ICEVs at 7 litres petrol, and EVs at 20 kWh, per 100km, consistent with the analysis in Sacchi et al. (2022). We assume no change in current pre-tax prices of each energy source, 0.90 CHF per litre in the case of petrol and 0.20 CHF per kWh in the case of electricity. In addition to the energy costs, we assume an amortized cost of the EV making use of a residential charger, at 200 CHF per year.

Table 1: Variables used to evaluate the different cost/benefits for EVs compared to ICEs. The different monetary values are in CHF, where 1 CHF equals 1.16 USD (July 2023).

Variable	Assumption(s)	Units	Reference(s)
Average vehicle lifetime	15	years	Held et al. 2021
Purchase price difference (base 2020)	9’000 (economy cars, linearly going down to 2’000 in 2030, then 0 in 2034), 4’000 CHF (mid-cost cars, down to -2’000, then -2’500), 500 CHF (premium cars, down to -5’000, then -6’000)	CHF	Authors’ owns estimation, based on Goezel and Hasanuzzman 2022
Maintenance cost difference	500	CHF/year	Liu et al. 2021
Resale value	0	CHF	AGVS 2022

Average yearly distance per car	15’000	CHF/year	BFS 2021; TCS 2023
Tires’ costs	One 1000CHF tires’ set every 4 years (ICEV), every 3 years (EV)	CHF/year	Authors’ owns estimation, based on Beddows and Harrison 2021
Tires’ and brakes’ emissions difference between EVs and ICEVs	0	gPM10/year	Authors’ owns estimation, based on Beddows and Harrison 2021, and Hall 2017
Charger and load manager for EVs	200	CHF/year	Energie 360° 2022
Registrations of new cars	242’000 for 2021, assumed to be constant after 2021	Units/year	BFS 2023a
Fuel price	0.9 (before taxes), assumed to be constant after 2023	CHF/l	BFS 2023c; BAZG 2023
Fuel consumption (petrol and diesel)	7	l/100km	Sacchi et al. 2022
Electricity price	0.20 (before taxes) , assumed to be constant after 2023	CHF/kWh	EnergieSchweiz 2023
Electricity consumption	20	kWh/100km	Sacchi et al. 2022

2.2 Indirect costs/benefits of the reduced air pollution and reduced CO_2 emissions

Beyond the direct costs/benefits of use, we consider the health costs of air pollution, as well as the costs of climate-related damage. One study at Swiss scale suggests that ICEVs currently generate additional health impacts relative to EVs at a cost of 500 CHF per car and per year (ARE, 2019). These costs are reported to the emissions of the current Swiss car fleet, including older cars that do not fulfil modern emissions’ standards like the Euro 6 emission standards. While our calculations are based on new cars that must comply to Euro 6 emissions standards since 2015 in Switzerland (OFEV 2015), the costs of local pollution are based on the state of the current fleet, which include older car that do not fulfil these standards. However, new ICEVs entering in the new Swiss fleet until 2035 will comply to at least Euro 6. Therefore, we have to take into account that older cars in the current fleet will be taken out of service, in our case after 15 years (Held et al. 2021). Thus, the overall emissions of the ICEV fleet will decrease since their emissions decrease of about one order of magnitude between the norms Euro 4 and Euro 6. As the detailed data of the aging Swiss cars' fleet are not fully available, we take values from Germany for our estimations (KBA 2022), where new cars represent about 5% of the total fleet each year. We therefore assume that the proportion of Euro 6 cars increases of 5% each year, starting from 30% in 2019 (KBA 2022), when the calculations of ARE (2019) have been made. Considering that Euro 6 cars are roughly one degree of magnitude cleaner than Euro 4 and before, we assume the pollution costs of the ICEV fleet emissions calculated by ARE (2019) decrease each year of 4.5%.

Local emissions of cars, and their health costs, also entail emissions of tires and brakes. There is evidence of substantial particulate-matter (PM) emissions due to cars' tires and brakes wear, both mainly in the same magnitude of Euro 5-6 emissions norms (Grigoratos and Martini 2014). While the wear-out of EVs' tires is higher due to higher car-weight, and thus the emissions of (PM) are increased (Beddows and Harrison 2021), emissions related to brakes' decrease due to the energy recovery during regeneration phases in the traffic (Hall 2017). However, due to the uncertainty of the current data on different in brake use between EVs and ICEVs, we conservatively assume that the emissions of the reduced brake use of EVs compensates the added wear out of EV's tires compared to ICEVs.

Regarding the climate change related costs, we use the cars' emissions' estimations provided by life-cycle assessment carried by Sacchi et al. (2022), which are specific for Switzerland and its vehicle fleet, multiplied by a social cost of carbon of 196.8 CHF/tonCO_2eq (Rennert and Kingdon 2022). We do this for an average yearly driving distance of 15'000 km, which is close to the average pre-COVID19 driving distance of Swiss drivers (BFS 2021). The resulting yearly cost of climate change related damages per car was 443 CHF per car and year. Similar to the local air pollution, we project these annual costs for the lifetime of the vehicle, with a discount rate of 3% (SNB 2023) to calculate a net present value at the time of vehicle purchase.

2.3 Market size and EV diffusion scenarios

Since Switzerland is geographically enclosed in the EU, we can assume that the Swiss car-market will directly follow European emissions standards, like it has been the case for the different Euro 1-7 norms (OFEV 2019). As the EU emissions standards are going towards emission-free new cars by 2035 (EC 2022), we focused only on the new cars' fleet in this study. We therefore assumed that the Swiss number of registrations of new cars will keep constant at the level of 2021, also considering that the age of the fleet has been growing in the past years (Auto-Schweiz 2022).

In the most recent year, 2022, 17.7% of new light vehicle registrations were electric (BFS 2023a), leaving a gap of 82.3% to be filled by 2035. For the case where a right-to-charge measure will be in place – our "best case" scenario – we fitted a logistic curve to the historic values. Figure 1 shows these fitted values, corresponding closely to observed values in Norway, which leads Switzerland by about five years in EV market share, and which has adopted a right-to-charge law. Figure 1 also shows a "worst case scenario", in which the adoption of EVs stalls around 2024-2026 at the level of the proportion of households that own an individual house. The curve then steeply catches up to the EU-goals by 2035. In between the two curves, we draw a curve with a linear diffusion rate. In all cases, we assume that the number of new vehicles registered in any given year remains at current values.

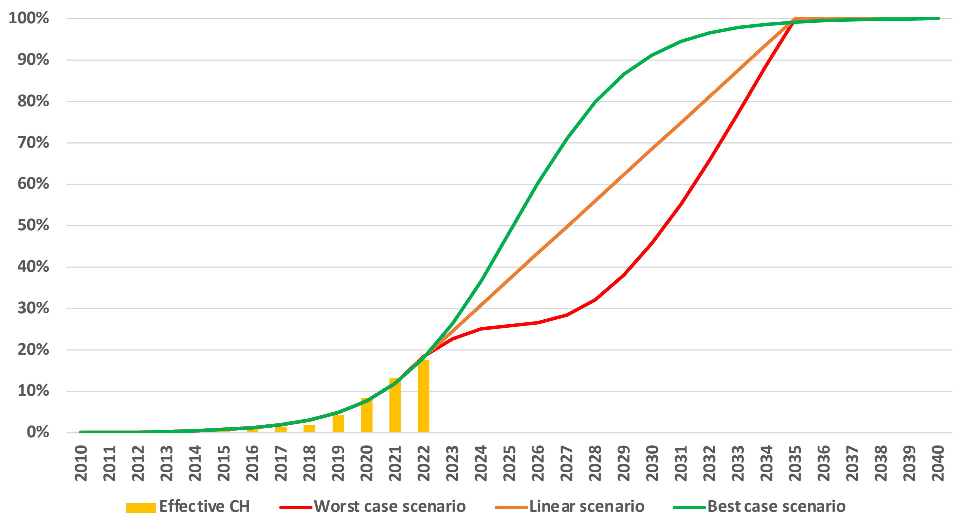

Figure 1: Proportion of the share of EVs in new registrations in Switzerland (BFS 2023a), and extrapolated projections towards 2035 through a (1) best case scenario (fleet adjusting the EU 2035 policy constraints), (2) a linear scenario (linear fit to the EU 2035 constraints), and (3) a worst case scenario, where EV-sales stall towards 2024-2026 due to the absence of a right to charge, but then pick up to reach the EU 2035 constraints.

2.4 Costs of accelerated infrastructure deployment

A right-to-charge law would affect not only the diffusion of vehicles themselves, and associated costs and benefits related to the vehicles, but would also require an accelerated updating of key infrastructure, to support the faster installation of EV charging. This would include both the retrofitting of wiring and installation of load management systems in apartment building garages, and the installation of on-street charging. In the latter case, recent experience in the UK suggests cost effective solutions, alleviated the need for digging, by making use of existing electrical conduits serving street lighting (Ubitricity 2023). The actual costs vary on a case-by-case basis, but based on industry guidelines we assume a low value of 1,000 CHF and a high value of 5,000 CHF per vehicle parking space (Ubitricity 2023 for the lower value; SEFA 2022 for the maximum value), and carry out calculations for both sets of analysis.

The Swiss vehicle fleet encompasses roughly 6.5 million vehicles (BFS 2023b), for a population of about 9 million people. We assume that with the complete diffusion of EVs, most of these, 5 million, will require its own dedicated charging point in the space where it is parked overnight. We assume that under the best-case scenario, the work to support the installation of 5 million chargers would take place evenly over the eight-year period from 2023 – 2030. Under the linear and worst-case scenarios, by contrast, the needed work would take place somewhat later. For the worst-case scenario, we assume that it would take place evenly over the eight-year period from 2028 – 2035. Under the linear scenario, we assume that it would take place evenly over the 13-year period 2023 – 2035. Ultimately the amount of work needing to be completed is the same in each scenario: what differs is when the work would need to be undertaken. This then influences the net present value (NPV) of the cost of that work. Hence, using two assumptions of 1,000 CHF and 5,000 CHF for each of the 5 million parking spaces, we compute the NPV of the work needing to be undertaken, discounted to the year 2023 at an annual discount rate of 3%.

There is also reason to believe that the diffusion of EVs, along with the concurrent diffusion of distributed wind and solar power generation, will require updates to local power distribution grids (Wangsness and Halse 2021). We acknowledge this work needing to be undertaken, but do not include it in our analysis. The reasons for omitting it are the challenge of estimating the total cost, the share of that cost attributable to the diffusion of EVs versus wind and solar power, and a lack of clarity concerning whether the main factor influencing the timing of these updates would be EV diffusion, or wind and solar power diffusion. We acknowledge this as a weakness to our study.

3 Results

3.1 Direct costs/benefits to the car owner

The lifetime costs/benefits of EVs compared to ICEVs are positive already today, where the additional purchasing cost of an EV are offset through lower maintenance costs and lower energy costs (see Figure 2). The total lifetime benefits EVs compared to ICEVs stabilize to around 11’000 CHF by 2030, until the phasing out of ICEVs. This is mainly due to the lower price of EVs in the future, especially for small EVs.

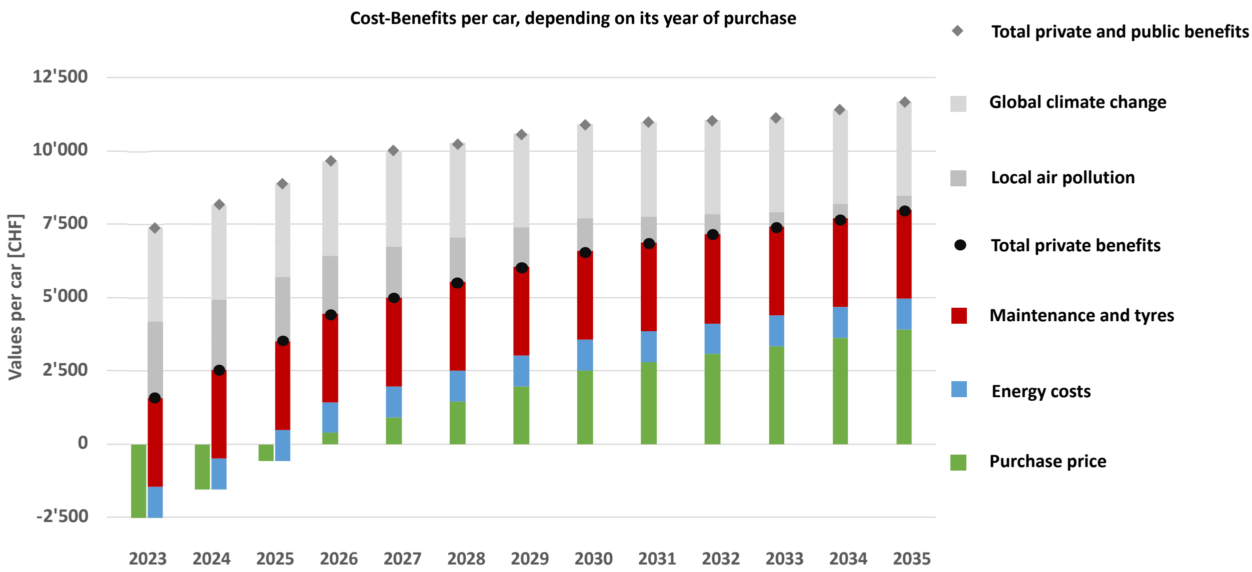

Figure 2: Costs and benefits in CHF for a new car purchased in different years towards 2035. The values are averages of the three car categories (economy, mid-cost, and premium). The circles represent the total private benefits over the lifetime of an EV over an ICEV. The diamonds represent the total private and public benefits over a lifetime of an EV compared to an ICEV. The different monetary values are in CHF, where 1 CHF equals 1.16 USD (July 2023).

3.2 Indirect costs/benefits of the reduced air pollution and reduced CO_2 emissions

When considering the whole Swiss fleet, we calculated the total costs/benefits for the “best case scenario”, where the adoption of EVs follows the target set for 2035 in a logistic form, as well for the “worst case scenario”, where adoption stalls by the mid-2020s (see Figure 1). The difference of these two curves represents the costs of a slower transition towards the 2035 target (see Figure 3). We also added the difference to the linear scenario, which is mid-way in between. The costs of non-transition peak in 2032 in both comparisons, with a peak value of 907 millions CHF for the beat-worst comparison, and 453 millions CHF for the best-linear comparison. The results also show that the initial negative values, i.e. a "gain" in non-transition in 2023-2024 are quickly offset by the non-transition costs of the following years.

The sum of these costs over the period 2023 to 2049 equals 11.9 billion CHF for the best-worst comparison (see Table 2), about 1.5% of the Swiss GDP (IMF 2023). For the best-linear comparison, the sum of the costs over 2023-2049 are substantially lower at 5.9 billion CHF. In both cases, the long tail after 2035 is due to the continuing use of ICEVs, as we planned a usage duration of 15 years in our calculations, and these vehicles will still be on the road until 2049.

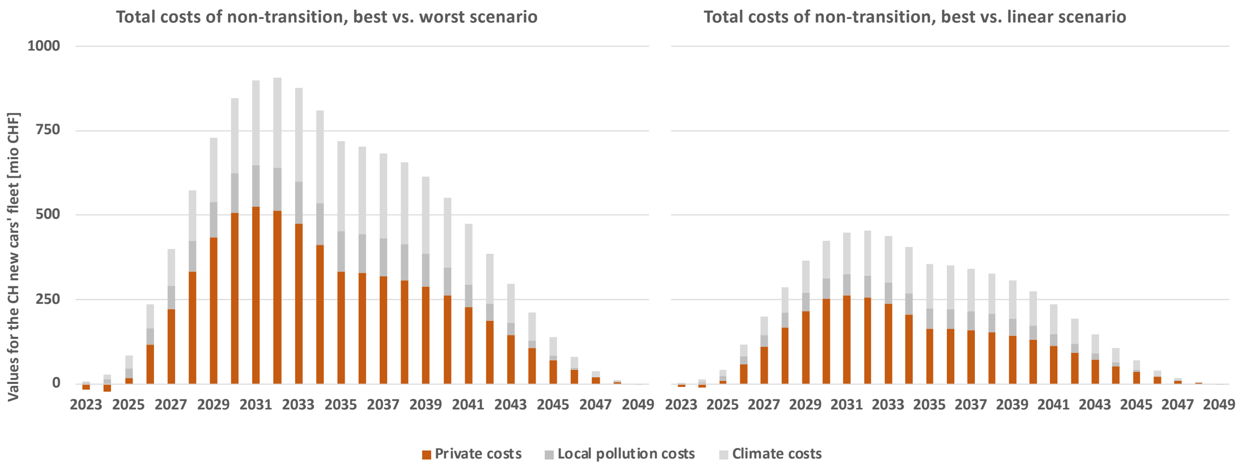

Figure 3: Total costs of non-transition per year from 2023 to 2049 (in mio CHF as a net present value for 2023), for the difference between the total Swiss passenger car fleet for the "best case scenario", where right-to-charge measures are in place, and the "worst case scenario", where the diffusion of EVs stalls due to the lack of these measures. The values are averages of the three car categories (economy, mid-cost, and premium). The different costs are calculated as NPV for 2023 with a discount rate of 3%. The different monetary values are in CHF, where 1 CHF equals 1.16 USD (July 2023).

Table 2: Net present value (NPV) of the yearly costs of non-transition in millions CHF from 2023 to 2049, as shown in Figure 3: private costs related to ownership, local pollution costs, and climate costs. The different costs and their totals (in italic) are calculated as NPV for 2023 with a discount rate of 3%. The different monetary values are in CHF, where 1 CHF equals 1.16 USD (July 2023).

	Fleet costs best vs. worst [mio CHF]					**Fleet costs best vs. linear [mio CHF]**				
Year	**Private costs**	**Local pollution**	***Local NPV***	**Climate costs**	***Total NPV***	**Private costs**	**Local pollutio n**	***Local NPV***	**Climate costs**	***Total NPV***
2023	-17	3.2	*-14*	3.8	*-10*	-8.4	1.6	*-6.8*	1.9	*-4.9*
2024	-23	13	*-10*	16	*5.7*	-12	6.5	*-5.0*	7.9	*2.8*
2025	17.8	28	*46*	38	*84*	9.4	15	*23*	19	*42*
2026	116	49	*165*	70	*235*	64	27	*83*	35	*117*
2027	221	70	*291*	108	*399*	124	40	*146*	54	*200*
2028	333	91	*423*	149	*573*	193	53	*212*	75	*286*
2029	433	107	*540*	189	*728*	258	64	*270*	94	*364*
2030	506	118	*624*	223	*846*	311	73	*312*	111	*423*
2031	524	124	*648*	249	*898*	332	79	*324*	125	*449*
2032	513	126	*640*	267	*907*	335	82	*320*	134	*453*
2033	475	125	*600*	276	*876*	319	84	*300*	138	*438*
2034	412	123	*535*	276	*810*	285	85	*267*	138	*405*
2035	333	119	*452*	267	*719*	233	85	*223*	133	*356*
2036	329	116	*444*	259	*703*	241	85	*222*	129	*351*
2037	319	112	*431*	252	*683*	241	85	*215*	125	*341*
2038	307	107	*414*	242	*655*	238	83	*206*	121	*327*
2039	288	98	*386*	227	*613*	230	78	*192*	113	*306*
2040	261	85	*346*	206	*552*	215	70	*172*	103	*275*
2041	227	69	*295*	179	*474*	192	58	*147*	89	*236*
2042	187	52	*239*	147	*386*	163	45	*119*	73	*192*
2043	146	36	*182*	115	*296*	131	32	*90*	57	*148*
2044	106	23	*129*	83	*212*	98	21	*64*	42	*105*
2045	71	13	*83*	56	*139*	67	12	*41*	28	*69*
2046	42	6.2	*48*	33	*81*	40	6.1	*24*	16	*40*
2047	20	2.4	*22*	16	*38*	20	2.4	*11*	7.6	*18*
2048	5.8	0.7	*6.5*	4.6	*11*	6	0.7	*3.0*	2.1	*5.0*
2049	-0.5	-0.1	*-0.6*	-0.4	*-1.0*	-1	-0.1	*-0.6*	-0.4	*-1.0*
Total [b. CHF]	**6.1**	**1.8**	***8.0***	**3.9**	***11.9***	**4.3**	**1.3**	***4.0***	**2.0**	***5.9***

3.3 Costs of accelerated infrastructure deployment

For the calculation of the infrastructure deployment, we estimated the values of the extremes of two scenarios: a fast deployment, mostly in 2023-2030, and a slower deployment in 2028-2035. These two scenarios aim to have 5 million charging points, which can cover most of the Swiss cars' fleet. We also considered a variation of the charging point installation-costs, with a minimal value of 1'000 CHF/spot and a maximum conservative value of 5'000 CHF/spot.

Our results are net present values for 2023 and show two contrasts (see Table 3): deploying the charging points slow compared to slow will have a total cost of 621 million CHF for the lowest chargers' costs, and 3.1 billion CHF for the expensive chargers' costs. These costs are relatively low compared to the non-transition costs related to the cars' fleet (see Table 3). However, they are a key to a fast transition towards EVs.

Table 3: Summary table of the costs of accelerated development of 5 million charging points across Switzerland. The development is assumed as either "fast" (2023-2030), or "slow" (2028-2035), with costs per parking spot of either 1000 CHF (low estimate), or 5'000 CHF (high estimate). All values are net present values to 2023, calculated with a discount rate of 3%. The different monetary values are in CHF, where 1 CHF equals 1.16 USD (July 2023).

Year	"Fast" spaces	"Slow" spaces	Total cost [mio CHF], fast at 1'000 CHF/spot	Total cost [mio CHF], fast at 5'000 CHF/spot	Total cost [mio CHF], slow at 1'000 CHF/spot	Total cost [mio CHF], slow at 5'000 CHF/spot
2023	625'000	-	625	3'125	-	-
2024	625'000	-	607	3'034	-	-
2025	625'000	-	589	2'946	-	-
2026	625'000	-	572	2'860	-	-
2027	625'000	-	555	2'777	-	-
2028	625'000	625'000	539	2'696	539	2'696
2029	625'000	625'000	523	2'617	523	2'617
2030	625'000	625'000	508	2'541	508	2'541
2031	-	625'000	-	-	493	2'467
2032	-	625'000	-	-	479	2'395
2033	-	625'000	-	-	465	2'325
2034	-	625'000	-	-	452	2'258
2035	-	625'000	-	-	438	2'192
		Total	4'519 mio CHF	22'595 mio CHF	3'898 mio CHF	19'490 mio CHF

Difference, Fast to Slow at 1000 CHF/spot	621 mio CHF
Difference, Fast to Slow at 5000 CHF/spot	3'104 mio CHF

4 Discussion

In this study, we show that a fast transition towards a fully decarbonized new cars' fleet entails substantial direct benefits to car owners, as well as social benefits. We showed in this study that the private benefits of owning an EV are already positive today, with a potential further increase compared to ICEV in the next years (1'500 to 8'000 CHF in 2035). We also showed that the local and global benefits are already overwhelmingly positive today (6'000 CHF), even if we consider that the ICEV fleet will be less polluting in the future due to current and new emission regulations. Over the full Swiss new-cars' fleet, we show that a quicker transition, compared to a linear evolution of the EV adoption towards 2025 will cost about 6 billion CHF to the Swiss society. This value increases to about 12 billion CHF when compared to a scenario where EV adoption stalls over time. Finally, we estimate that a massive charging network development would cost substantially less than the costs of a slower transition towards EVs. A delay in the development of the charging network is also relatively inexpensive, but the infrastructure is key to an EV transition, which can only happen fast enough if there are measures in place to provide all households where cars are used with the opportunity to charge overnight.

The results we provide in this study are depending on the assumptions we made, and this may pose some limitations. First, the extrapolation we carry out for the time between 2023 and 2035 is mathematical, although bounded by constraints that are likely to happen, like the EU phasing out ICEVs for the mass market (EC 2022), or the recent decision of the Swiss people to reach carbon neutrality by 2050 (BK 2023). Second, we assumed that the size of the new cars' market would remain stable after 2022. While the car market depends on the evolution of the modal split in Switzerland, we consider unlikely that the reduction of the use of cars in urban areas compensates a continuing need for individual mobility in rural areas. Third, the evaluation of the pollution costs and for the climate-induced costs rests on relatively larges uncertainties (ARE 2019). Nevertheless, the results of this study provide a plausible extrapolation on where the car market may be going if we do or do not adopt additional measures to foster EVs beyond what is already in place today.

Other results available in the grey literature attempted to model the evolution of the EV adoption towards 2035. For instance, Swiss eMobility (2021) modelled the evolution of the Swiss EV-fleet to evaluate the additional electricity consumption needed for the Swiss cars' fleet (10.7%). However, while they also used an optimistic and pessimistic scenario, they did not evaluate the costs that a faster or slower transition towards 100% EVs. In their case, the pessimistic scenario they use does not entail a possible "stall" towards 2025-2027 like we start to observe today (Etienne 2023), and their pessimistic scenario is therefore more similar to our linear scenario. Their approach is in line with the idea that no large policy measures are needed to further push the adoption of EVs, since Switzerland is attached to Europe and will benefit of the European "EV megatrend" pulled out by other countries, for instance Norway or the Netherlands. However, these two countries have a substantially higher house ownership ratio, Norway 80.8% and Netherlands 70.1%, compared to Switzerland with only 42.3% (Statista, 2022). Since the possibility of charging at home is key for the adoption of EVs, the difference in ownership ratio of Switzerland could cause a stall in EV adoption, even if at the moment all adoption curves point upwards. Brückmann et al. (2021) inquired on this factor for Switzerland, and home ownership is one the factors that predict EV adoption after income, technology affinity, partisan affiliation and car sharing. In their study, "charging availability" was the number of charging spots per ZIP-code, and showed to have no influence on EV adoption. In our case we stress the possibility to charge at home as a key-element to EV diffusion. Additional measures may therefore help most of the population who does not own their home to be able to do so, potentially avoiding a stall that may delay a necessary transition, with an additional economic cost for the Swiss society.

The type of right-to-charge measures that are necessary to overcome the lock-in for apartment dwellers in Switzerland goes beyond the scope of this study. It is however uncertain whether these measures are needed, considering the potential ability of the private sector to deploy the necessary charging infrastructure as it did so far. Nevertheless, the experience from other countries where the diffusion of EVs is more advanced than in Switzerland shows that a certain degree of enforcement for charging infrastructure will be needed to overcome current market failures. And if the private sector makes it to reach the levels of infrastructure observed in other countries, right-to-charge measures will have no costs but would act as a policy safety-net in case the transition towards EVs stalls.

Measures to accelerate the development of charging access will have to be designed according to the different competencies of the public and market actors in Switzerland, and also according to what is technically feasible. This last technical point is also relevant, since the technology for overnight charging is not the same as what can be found in public charging stations. In the case of overnight parking, slow charging devices may be more adapted, since cars often stay parked for a long period of time over the day, usually beyond the duration of a night (Tchervenkov 2022). Having the opportunity of charging at a household scale can substantially shift the Swiss' new car market towards EVs. Our results suggest that new policy measures to support charging at home can enable a quicker shift to a carbon-free mobility at an affordable price, and any delays in this transition will cause social costs that could be avoided in the near future.

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