Local Benefits Exceed Costs For Widespread Charging Infrastructure For On-Street Urban Parking

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Abstract

Background

Lack of charging infrastructure is a critical barrier to the dissemination of electric cars and many cities have started installing charging stations in public parking spaces.

We do a cost-benefit analyses of installing charging stations in public parking spaces, with different assumptions for uptake of electric cars, topology of charging stations, environmental benefits, and costs for infrastructure. We use the case study of Zurich, which is representative of dense European cities.

Results

We find that building charging stations in residential areas has net positive benefits, as long as the charging stations are used at least one-third of the daytime. Net benefits remain positive if we remove noise or climate benefits.

Conclusions

Aiming to equip 40% of public residential parking spaces with charging points, and then accelerating or slowing down the deployment of charging stations based on their actual use appears to be a robust strategy that will result in positive net public benefits for city residents and stimulate uptake of electric cars.

Highlights

- Cost-benefit analyses of installing charging stations in public parking spaces
- Aiming to equip 40% of public parking has net positive benefits for a large city
- Adjusting deployment of charging stations based on their use is a robust strategy
- Net positive public benefits remain without noise or climate benefits

Introduction

Transport is one of the sectors that contributes most to global energy consumption and greenhouse gas emissions. Within this, the passenger car market is currently dominated by internal combustion engine vehicles (ICEV), which depend on fossil fuels. However, a switch to more environmentally friendly fuels and powertrains is essential in a transition towards a sustainable transport system.

Electric vehicles (EV) have the potential to improve the air quality [1] as well as reduce greenhouse gas emissions and urban heat island effects [2–6]. EV also reduce noise pollution at low speeds [3, 7]. Although EV have many advantages, their use is still very modest.

One critical barrier to the dissemination of electric cars is lack of charging infrastructure. Melliger et al. [8] have shown that charging stations at home and in residential areas are very important: Home charging gives users the security of having a sufficiently charged battery at their disposal. Baresch et al. [9] modelled demographic variables and decision rules and found that 88% of charging is carried out at home. However, home charging is often not practicable in cities and urban areas, as many tenants do not have their own parking space where they could install a charging station. Lack of charging options seems to be a reason why people do not buy an electric car [10]. To close this gap, many cities, like Oslo and Amsterdam, have started installing charging stations in public parking spaces [11, 12]. Furthermore, private companies like Green Motion SA [13] or MOVE Mobility SA [14] have started up that offer to build the charging infrastructure in exchange for revenue-sharing. This suggests that there is a business case for charging infrastructure for EV.

To help determine if installing charging stations in public parking spaces is a sensible policy, we analyse the costs and benefits if a large-scale rollout of charging stations in residential areas in the city of Zurich, Switzerland. Zurich has the potential to be a leading city in EV adoption, as it has well-maintained infrastructure, the driving population spend above-average amounts of money on their vehicles [15] and therefore more likely to be able to afford the higher upfront costs of driving EV. However, 90% of Zurich residents are tenants [16], and therefore have limited opportunity for installing private chargers at their home.

We discuss existing literature and its shortcomings in Sect. 2, our methods and data in Sect. 3, show and discuss results in Sect. 4, and present our conclusions in Sect. 5. Overall, we find that benefits of installing charging infrastructure mostly outweigh the costs for the city of Zurich. Aiming to equip 40% of public residential parking spaces with charging points, and then accelerating or slowing down the deployment of charging stations based on their actual use appears to be a robust strategy that will result in positive net benefits.

Background

Many countries have targets to reduce greenhouse gas emissions from transport, and EV have emerged as an important technology to achieve that reduction. However, government targets for EV uptake do not correlate with implementation of policies to stimulate said uptake [17]. Access to charging infrastructure has been found to be a driving factor in the adoption of EV [10, 18]. Planning of parking spaces and usage etiquette play a role in this access [19] but the number of charging stations in an area set a hard limit on how many EV can be charged and how easy it is to find an available charging station. That leads to the question of who should install and pay for this infrastructure, especially for charging stations at parking spaces on public roads that will be shared by local residents and visitors, and whether the benefits outweigh the costs. The question of whether the local benefits outweigh the local costs is important primarily for the question of whether the use of public funds for the purpose of building charging stations represents a win-win option. This creates a strong argument for using public funds, which would probably accelerate the diffusion in advance of market forces. Even if the local costs are higher than the local benefits, it may still make sense to install them, including with public funds. For example, it will make it easier for city residents to enjoy the benefits of EVs relative to ICEVs, including (in the near future) their lower cost. In this case, however, it would represent a transfer from city taxpayers to EV owners.

This has been studied for cities in Europe and elsewhere. [Otter NH, Bauer; M. Schnitzler 20] studied Klagenfurt (Austria) and found that large numbers of EV are needed for net positive benefits of public charging stations. [EBP 21] suggest creating EV-only parking spaces to improve occupancy and lower net costs for Basel (Switzerland). Faria et al. [22] found that high parking prices and high occupancy increased economic feasibility of charging stations in public parking spaces in Minneapolis and New York (USA), Lisbon (Portugal), and Madrid (Spain). While these factors are obviously important, none of these studies was explicit about the number of charging stations that may be needed. Massiani et al. [23] simulated policies to promote adoption of EV in Germany without specific city context, and found net negative benefits for most of the tested policies. However, we find that no sufficiently detailed CBA exists at the level of a single city to support decision-making.

The number of parking spaces that should be equipped with charging stations to facilitate seamless EV driving depends on the number of EV but a share of 20% has been suggested for large-scale EV uptake [24]. Many studies also exist that calculate the optimal distribution of parking spaces with charging stations across a city [e.g. 25]. We chose a practical approach and use the on-street parking spaces in the residential areas of Zurich that are generally designated as 'blue zone' [26], which make up half of the public parking spaces in Zurich [City of Zurich et al., 201727]. 'Blue zone' parking distinguishes between residents and visitors: Residents can purchase a one-year parking permit that allows for unlimited parking within the 'blue zone' inside the resident's district, and visitors are allowed to park for free for 60–90 minutes (depending on the time of arrival), according to annex 3.1 of the Swiss signalization regulation [28]. After these 60–90 minutes, visitors have to move their cars or face a fine. More permits are sold for 'blue zone' parking than there are spaces [29], which indicates that demand for on-street parking in Zurich outstrips supply.

The 60–90 minutes parking time roughly matches the time needed to top up an EV, assuming that the charging stations are sufficiently powerful [also see 30]. A benefit of using the 'blue zone' parking spaces is that these can provide access to charging for both visitors (mostly during the day) and residents (mostly in the evening and at night). The 'blue zone' system, and a general high demand for parking, have made residents of Zurich used to changing parking spaces regularly and also to walk some distance from and to the nearest available parking space at their destination.

Ajanovic and Haas [31] suggested that any subsidies or economic support for EV should be contingent on the electricity sources. This is not a limiting factor for Zurich, as its electricity is sourced almost entirely from low-carbon nuclear- and hydropower [32].

Methods

We use cost-benefit analysis (CBA) [23, 33] to compare three scenarios for the market penetration of EV and concurrent expansion of charging infrastructure in the city of Zurich. Our study covers the costs and benefits from 2020 to 2050. The costs include installation costs, for charging station, power cable including digging, grid fees, signage and execution of construction work, as well as annual operating and maintenance costs for 22kW charging stations with two charging points. We considered the reduced impacts of EV compared to ICEV in a city, with reduced costs from climate, noise, human health, and building damage due to air pollution as benefits for the CBA.

We did not take into account potential costs and benefits of increasing electricity production, reduced plant growth, biodiversity losses, private costs like higher acquisition costs and reduced maintenance costs for EV, and indirect economic impacts like changes in travel behavior and employment in the automotive sector.

3.1 Scenarios and Strategies

We developed 3 different scenarios for the market penetration of EV up to 2050 (see Fig. 1):

- *Fast* scenario: By 2035 electric cars will account for the entire new car market (s-shaped uptake)
- *Gradual* scenario: By 2050 electric cars will account for the entire new car market (s-shaped uptake)
- *Slow* scenario: By 2050 electric cars will account for half of the new car market (linear uptake)

The current situation and expected development in the transport sector in the city are summarized in Table 1. Except for the number of passenger cars and the newly registered EV in Zurich, we suppose that these numbers will stay constant over time.

Table 1
Current situation and expected development in the transport sector in the city of Zurich.

	Value	Source
Total passenger cars in Zurich 2016	138 701	[34]
Average annual growth rate of total fleet 2006–2016	0.48%	[34]
Annual replacement of the total fleet	7.5%	[35]
Share of newly registered EV in the canton of Zurich 2016	3.2%	[35]
Number of parking spaces in 'blue zone' in Zurich 2017	33 400	[34]
Average daily distance per person	36.8 km	[36]
Average energy consumption of EV	0.2 kWh/km	[7, 37]
Most common charging capacity of a battery	11 kW	[12, 38]
Average loading time after one day	40 minutes	Own calculation

In order to save costs, it is not necessary to electrify all 33 400 parking spaces in the 'blue zone' reserved for residents' parking [39]. We developed 3 different strategies that indicate how many percent (20%, 40% or 60%) of the parking spaces in the 'blue zone' will be equipped with electric charging stations. We recognise that availability of charging stations and EV uptake are positively correlated [10, 18], but we also want to analyse what may happen if charging policy and EV uptake run out of step. One charging station can charge two cars at the same time, so depending on the strategy, 3 340 (20%), 6 680 (40%), or 10 020 (60%) charging stations will be needed to be built in 2050 in Zurich. Furthermore, it does not make economic sense to install all charging stations right from the start. They will be introduced in step with the increasing market penetration of EV, assuming the same pattern as the market penetration of EV (see Fig. 1). We assume that all charging stations can be built and installed within the corresponding year.

Based on our driving and EV assumptions (see Table 1), every driver needs an average of 40 minutes to recharge the electric car after an average day. Furthermore, drivers will have to leave or move to a different parking space to free up the charging station for the next vehicle. For this reason, we only look at the 'blue zone' on-street parking spaces in the residential areas of Zurich. Given that visitors are allowed to park for free for a total of 60–90 minutes, and charging needs an average of 40 minutes, a visitor would then have another 20–50 minutes of legal parking time remaining.

If few people in the city drive electric cars, the charging stations are likely to be less occupied than if many people drive an electric car. We therefore assume a different changeover time until the charging station will again be occupied by another EV, depending on the scenario. In the fast scenario the changing time is 10 minutes, in the gradual scenario 15 minutes and in the slow scenario 20 minutes. Because we assume the number of EV and charging stations grow at the same rates, the occupancy ratio of the charging stations is constant. We assume that the EV will not be moved at night between 8pm and 8am. Because more parking permits are sold than there are available parking spaces (City of Zurich, 2019b), we assume that all parking spaces are occupied with EV during the night. During the remaining 12 hours a day, we assume that successive EV will be charged in each space for the average charging time (40 minutes) and the additional changing time (10, 15 or 20 minutes depending on the scenario). As long as the maximum number of chargeable EV exceeds the number of EV in 2050 in each scenario, it will be theoretically possible to fully charge all EV in the city every day with regular changes.

3.2 Costs

We assume charging stations that can be used by two EV and provide a maximum of 22kW per charging point. Connection fees and costs for digging work mainly depend on the cable length (IWB, 2012). In order to save costs, it makes sense to place the charging stations to the transformer stations as close as possible. The costs also vary depending on the maximum transmittable power of the cable. We estimated the required cable length and the transmittable power as follows:

There are about 1 000 transformer stations in the city of Zurich [40]. Depending on the strategy, more or fewer charging stations are connected per transformer in a branching pattern (see Fig. 2 for topologies). The charging stations are distributed around the transformers at approximately the same distance from each other. As the charging stations branch out more in the 60% and 40% strategies compared to the 20% strategy, we increase the distance between each charging station and/or transformer to keep the same average distance (see Fig. 2). The capacity of the cables in between charging stations depends on how many charging stations are in series (see Fig. 2).

We assume that the 1 000 transformer stations are distributed evenly throughout the city, which we conceive of as a square of 32 by 32 transformers for simplicity. The real city of Zurich has a complex 3D topography and zoning, and the density of transformers is higher in high-density neighbourhoods compared to lower-density suburban neighbourhoods [41]. Given that the area of the city Zurich is 91.9 km² (City of Zurich, 2019c), we assume an average distance between transformers of 300m, which would cover an area of 92.16 km². Furthermore, we assume for simplicity that the EV parking spaces are distributed equally around the transformers in the city. In case of the 60% strategy, all of the city is within 59m of two charging points (see Fig. 2). In the 40% and 20% strategies, instead of spreading the charging stations evenly around the city, we concentrate these around the transformers to optimise cable costs and maintain a similar distance between charging station; The maximum possible distance to a charging station is approximately 120m between topology 1 stations in the 20% strategy, and this diminishes as more stations are added. A power cable has a lifespan of around 50 years [38], so power cable costs and construction work are included during installation only once.

As between 22 and 520 charging stations are built per year in the different scenarios, we assumed this high volume would result in a reduction of 40% for the costs of a charging station and the signage [38]. The annual maintenance costs for a charging station consist of CHF 450 for maintenance and CHF 288 for invoicing [38]. The total annual operating and maintenance costs thus amount to CHF 678 per charging station (see Table 2). In a similar project in the city of Basel, the lifespan of a charging station was estimated to be 5 years [38]. We therefore assume that the charging stations are replaced every 5 years at a cost of CHF 4 160 per charging station. Average total installation costs for one charging station range from CHF 36 652 in strategy 20%, to CHF 46 965 in strategy 60% (see Table 2). We assume that the costs will stay the same.

Table 2
Annual operating, maintenance and installation costs per charging station for strategy 20% 40% and 60% according to Sollberger [38] and IWB [42].

	Strategy 20%	Strategy 40%	Strategy 60%
Annual operating and maintenance costs per charging station [CHF]	678	678	678
Installation costs [CHF]	4 160	4 160	4 160
- Charging station (2x 22kW) incl. 40% discount			
- Power cable including digging (depending on cable length and power)	10 289	14 762	17 968
- Grid fees at network level 7 (CHF 100 /kWh)	4 848	6 824	7 483
- Signage incl. 40% discount	1 200	1 200	1 200
- Execution of construction work incl. third-party companies	16 155	16 155	16 155
Total average installation costs per charging station [CHF]	36 652	43 100	46 965

3.3 Benefits

EV have many advantages when comparing with ICEV (see Table 3). The total benefit of EV over ICEV is CHF 4 per 100 pkm. In a cost-benefit analysis in Klagenfurt, Otter et al. [20] calculated with saved costs of € 3 per 100 pkm.

Table 3
External costs (incl. range) of ICEV compared with EV in a city in Switzerland [43].

Benefit	Used value [CHF / 100 pkm]	Minimum value [CHF / 100 pkm]	Maximum value [CHF / 100 pkm]
Climate	1.3	0.702	2.340
Noise	0.5	0.320	1.100
Human health due to air pollution	2.2	1.320	5.370
Building damage due to air pollution	0.2	0.148	0.252

As the electricity production mix in Switzerland has very low emissions [32], we assume climate benefit equal to all of the greenhouse gas emissions from fossil-fueled cars.

Up to a speed of 30 km/h, EV are quieter than cars with combustion engines (Okoshi, 2011). At higher speeds, tire-road noise predominates (Jochem, 2015) and EV no longer have a significant noise advantage. Since half of the road kilometers in the city of Zurich are driven at speeds below 30 km/h [44], we assumed benefits of half the noise costs of CHF 1 / 100 pkm, resulting in CHF 0.5 / 100 pkm (see Table 3). In addition to engine and tire noise, the European Commission [45] requires an “Acoustic Vehicle Alerting System” (AVAS), a sound-generating device that should make EV safer for pedestrians and visually impaired people. ICEV cause a noise of 70–80 dB even at low speeds [46] and EV have to make a noise of 56 dB when driving at speeds up to 19 km/h as of 2019 [46]. According to annex 3 of the noise protection regulation in Switzerland [47] the immission value in the residential area for road traffic is 60dB during the day. As the required 56 dB are below the immission limit value, they are not included in our analysis.

Despite quieter driving, electric cars do not cause more accidents [7] and we therefore assume no net benefits or costs for accidents. Private costs (higher acquisition costs, reduced maintenance costs, etc.) and indirect economic impacts (changes in driving behavior, employment in the automotive sector, etc.) are not taken into account. Electricity costs are not included because they are paid by drivers to the electricity supplier. They are therefore neither a revenue nor an expenditure for the city. We did not take the effects of the increasing demand for electricity or the production of EV into account. Costs due to reduced plant growth, biodiversity losses and crop failures are not included because they are negligibly small in the city of Zurich [48].

After weighing up the different costs and benefits, the whole effect of the project for the different scenarios and strategies can be summarized with the calculation of the net present value (NPV). This NPV is computed using a 3% social discount rate [23].

Results And Discussion

Depending on the scenario, there will be between 52 200 and 132 900 electric cars in 2050 (see Table 4). The fast and gradual scenarios with 20% do not result in enough charging stations to charge all EV of the city (see Table 4), so we will include but not discuss these in further analysis.

Table 4

Number of EV that could be charged with the charging stations in the city for every scenario and strategy compared with the actual number of EV according to the scenario. In the fast and gradual scenario 20% the ratio of maximum chargeable EV to the actual number of EV are smaller than 1, they are included but not discussed in the further analysis.

Scenario and strategy	Maximum number of rechargeable EV per 24h	Projected number of EV in 2050	Ratio of maximum chargeable EV to actual number of EV in 2050
20%	102 600		0.8
Fast 40%	205 200	132 900	1.5
60%	307 800		2.3
20%	93 900		0.9
Gradual 40%	187 800	106 800	1.8
60%	281 700		2.6
20%	86 600		1.7
Slow 40%	172 300	52 200	3.3
60%	259 900		5.0

The total benefit only depends on the number of EV and is therefore the same per scenario (see Fig. 3). The costs vary according to the scenario and strategy. The more charging stations are installed, the higher the costs. The costs of the scenarios do not differ greatly per strategy, while the benefits vary greatly depending on the scenario (see Fig. 3). The total cost for the fast scenario 40% is just under 438 million over a period of thirty years (see Fig. 3). This is an annual investment of around CHF 14.6 million. If all new cars sold in 2050 would be electric (gradual scenario), the total cost would be CHF 397 million to electrify 40% of the parking spaces (see Fig. 3). This equates to CHF 13.2 million per year that the city of Zurich would have to spend on such a project. By way of comparison, the sale of annual parking cards in the ‘blue zone’ in 2018 generated revenue of CHF 13.1 million for the city [26, 29]. It should also be noted that the benefits in the fast and gradual scenarios with 40% electrified parking spaces exceed the costs. In the fast scenario 40% the city would make a profit after 11 years, in the gradual scenario 40% the city would make a profit after 13 years.

The benefits are greater than the costs in five out of seven scenarios. NPV is negative in the slow scenario 40% and 60%, in which a large-scale rollout of charging infrastructure is not met with a similar growth in EV using that infrastructure (see Fig. 4). NPV for the gradual scenario 60% is close to zero, and which makes it sensitive to reduction in benefits or cost overruns. This suggests that building out charging infrastructure is overall beneficial as long as the ratio of maximum chargeable EV to actual number of EV is maintained between 1 and 3 (see Table 4), i.e. enough charging stations are built to charge all EV and some to spare, as long as they are used at least one-third of the daytime on average.

Mitigation of GHG emissions is contingent on use of low-carbon electricity and does not immediately, directly and specifically benefit only the people of Zurich, and to explore how views on climate mitigation or electricity sources may change the cost-benefit evaluation, we calculated benefits excluding emission reductions (see Table 5). We find that the NPV in the gradual scenario 60% becomes negative in this case but the other four scenarios that had a positive NPV before still have a positive NPV.

Due to AVAS it may be that in future EV will no longer be quieter than ICEV. Again, NPV in the gradual scenario 60% becomes negative without noise benefits, but other four stay positive (see Table 5).

Table 5

NPVs (in million CHF) of all scenarios and strategies if the benefit (CHF / 100 pkm) changes. The ranges of the climate, noise, human health and building damage are according to the numbers of ARE [43].

		Climate original value: CHF 1.3 / 100pkm			Noise original value: CHF 0.5 / 100pkm			Health original value: CHF 2 / 100pkm		Building damage original value: CHF 0.2 / 100pkm	
	original NPV [million CHF]	0	0.702 [CHF/ 100pkm]	2.34 [CHF/ 100pkm]	0	0.32 [CHF/ 100pkm]	1.1 [CHF/ 100pkm]	1.12 [CHF/ 100pkm]	4.88 [CHF/ 100pkm]	0.148 [CHF/ 100pkm]	0.252 [CHF/ 100pkm]
Fast	531.1	318.7	433.4	700.9	449.4	501.7	629.1	387.3	1001.6	522.6	539.6
20%											
40%	380.0	167.7	282.3	549.9	298.4	350.6	478.1	236.3	850.5	371.5	388.5
60%	217.5	5.1	119.8	387.4	135.8	188.1	315.5	73.8	88.0	209.0	226.0
Gradual	278.3	154.9	221.5	376.9	230.8	261.2	335.2	194.8	551.4	273.3	283.2
20%											
40%	151.6	28.3	94.8	250.2	104.1	134.5	208.5	68.1	424.7	146.6	156.5
60%	14.7	-108.6	42.0	113.3	-32.7	-2.4	71.6	-68.8	287.9	9.8	19.6
Slow	107.9	36.7	75.1	164.8	80.5	98.0	140.7	59.7	265.6	105.0	110.6
20%											
40%	-30.3	-101.5	-63.1	26.6	-57.7	-40.2	2.5	-78.5	127.4	-33.2	-27.5
60%	-179.3	-250.5	-212.1	-122.4	-206.7	-189.2	-146.5	-227.5	-21.6	-182.2	-176.5

In the fast scenario 40% and 60%, the gradual scenario 40% and the slow scenario 20%, the NPV is always positive (see Table 5) and provide enough charging stations for all EV in the city (see Table 4).

We also analyzed the sensitivity of costs and benefits to car efficiency (kWh/km), distance driven (pkm/d), changing time, charging station capacity (kW), cable length, discount rate, and lifespan of the charging stations. None of these factors make a qualitative difference in outcomes, and the results can be found in the annex. We did not test our assumption of evenly distributed transformers, but we argue that the need for EV charging is probably greater in high-density areas, leading to heterogeneity in density of charging stations, as well as cable lengths and costs, but not necessarily much higher total costs.

We found that the installation of charging stations with public funds in Zurich would represent a win-win situation as the local benefits exceed the local costs: Residents of Zurich would get a net benefit from lower noise, better health, and less damage to building by paying for charging stations to make it easier for city residents to enjoy the benefits of EV relative to ICEV (i.e. wins). The owners of electric cars also benefit from having charging stations paid for (i.e. they win too). This creates a strong argument for using public funds to accelerate the diffusion of EV in advance of market forces.

If the city wants to cover the expenses without subsidizing the benefits of reduced GHG emissions, noise and air pollution costs, a fee per kWh can be charged to cover project costs. The city dwellers would have to pay CHF 0.03 to 0.33 per kWh for the use of charging stations (see Table 6). With an electricity price of CHF 0.21 per kWh (ElCom, 2019) and an average consumption of 0.2 kWh/km, drivers would have to pay between CHF 4.7 and 10.7 for 100km of driving, compared to CHF 9 to 15 per 100km for fossil-fueled cars. If the city of Zurich operates the charging stations and charges only for the electricity used, drivers would only have to pay CHF 4.03 per 100 pkm.

Table 6

Electricity consumption of all EV from 2020 to 2050 is the same for each scenario. The fee is the price per kW charged that car drivers must pay in addition to the electricity price so that an external company could cover the cost of installing and maintaining charging stations and providing electricity.

Scenario and strategy	Electricity consumption of all EV from 2020 to 2050 [GWh]	Costs of the project [millions CHF]	Fee (in addition to the electricity price) [CHF/kWh]	Costs for drivers [CHF/100pkm]
20%		197	0.03	4.70
Fast 40%	5 890	438	0.07	5.51
60%		695	0.12	6.39
20%		177	0.05	5.02
Gradual 40%	3 570	397	0.11	6.25
60%		634	0.18	7.58
20%		185	0.09	5.90
Slow 40%	1 980	414	0.21	8.20
60%		659	0.33	10.68

With an annual electricity consumption of around 3 000 GWh for the city of Zurich (2019a), electricity consumption would increase by 2.13% (slow scenario), 3.83% (gradual scenario) or 6.33% (fast scenario) per year.

Having sufficient drivers switch to EV so that the reduced external costs cover costs of installing and maintaining charging stations is essential. However, this should not detract from pursuing other options for sustainable mobility: Bicycles and public transport have even high benefits than EV. To ensure that not all dwellers change from the public transport to EV there should not be installed too much charging stations. Furthermore, the slow scenario is not compatible with local policy because the city of Zurich has set itself the target to become a 2000-Watt society [49] and Switzerland has ratified the Paris climate agreement [50]. Considering the limits encountered with the 20% strategy (too few charging stations in the fast and gradual scenarios) and the 60% strategy (too expensive in the gradual and slow scenarios), it makes sense to initially follow the strategy of installing charging stations in 40% of the parking spaces. In this strategy 40% between 348 and 444 charging stations would be built per year, compared to Oslo currently installing 200 charging stations a year [51]. These numbers therefore seem feasible with good planning, preinstallation, and monitoring. Careful planning and installation can also support the efficient use of these new charging stations [see 19].

We chose 22kW charging stations in 'blue zone' parking spaces because this arrangement of charging stations close to homes fits the existing situation in the city of Zurich. Also, most people prefer to charge their cars at home (Melliger et al., [8], current EV owners overwhelmingly do so (Baresch et al., [9], and lack of charging at home could be a reason for people not to buy an electric car [10].

Other strategies are also possible. For example, a city could focus on charging at popular stops or destinations, like service stations, shopping centres, or other major venues. Mixed strategies are also possible. The city of Amsterdam has 2 750 normal charging stations and 19 fast chargers [11]. A small number of fast chargers on locations with high vehicle turnover could reduce the number of stations that are needed but, according to the city of Oslo [12], it is not yet clear whether owners of electric vehicles prefer to charge slowly or fast (between 50kW and 180 kW). Baresch et al. [9] suggest that only 1.5% of charges are currently conducted at fast chargers.

Much of this analysis should apply to other cities as well, but urban density is a major factor in both costs, as costs for digging and laying cables depend on spacing between transformers and charging stations, and benefits, as the number of people affected by noise and air pollution depends on density of inhabitants. By contrast, the reduction of GHG emissions increases as a city is sparser and therefore requires more driving. Overall, we expect that dense cities with high demand for on-street parking, as found in much of Europe, will see similar results in

a CBA of installing charging stations in public parking spaces, but the NPV will be lower in areas of (sub)urban sprawl, as common in North American cities.

Summary And Conclusions

We analysed the costs and benefits of a large-scale rollout of charging stations at on-street parking spaces in residential areas in the city of Zurich, Switzerland. Charging infrastructure seems to be a precondition for city dwellers who do not have their own parking space to switch to EV. We find that building charging station in residential areas has net positive benefits, as long as the charging stations are used at least one-third of the daytime. Aiming to equip 40% of public residential ('blue zone') parking spaces with charging points, and then accelerating or slowing down the deployment of charging stations based on their actual use appears to be a robust strategy that will result in positive net benefits for the city of Zurich. We expect this strategy to have net positive benefits in other dense cities with high demand for parking as well. Furthermore, this result does not change if we do not consider noise or climate benefits, so the same applies to cities who do not consider climate change mitigation a priority.

Declarations

Ethics approval

Not applicable, no human or animal data was directly used in this study.

Availability of supporting data

CBA calculations can be supplied on request, all other data is either publicly available or included in this paper.

Competing interests

The authors declare that they have no competing interests

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Authors' contributions

Malenka Schmutz and Oscar van Vliet were involved in all aspects of the paper, Tony Patt was involved in conception of the work, interpretation of the data, and editing the manuscript.

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Figures

Figure 1

Number of EV in the city of Zurich from 2020 to 2050 in the fast, gradual and slow scenario.

Figure 2

Assumptions for topology of charging stations around one transformer for every strategy. Further there is the number of how many of these schemes are used in every strategy so that the number of charging stations are distributed equally around the 1'000 transformer stations in the city. The required capacity (44kW, 88kW, 132kW or 176kW) of the cables is marked with different lines.

Figure 3

Sum of all benefits and costs (not discounted) from 2020 to 2050 for all scenarios and strategies. Benefits are positive and the costs are negative. The fast and gradual scenario 20% are not shown because they do not offer enough charging stations.

Figure 4

Net present values in million CHF for all scenarios and strategies (without the fast and gradual scenario 20% because they do not offer enough charging stations) including its range. Without the climate benefit (CHF 0 / 100 pkm) the NPV always reaches a minimum (see table 5, column 2). If the benefit of reduced air pollution to human health is bigger than we assumed (CHF 4.88 / 100 pkm) the NPV reaches a maximum in all combinations of scenario and strategy (see table 5, column 8).

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