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The long-term effects of COVID-19 Lockdowns on electric vehicle charging behaviour

Mylène van der Koogh[1,2], Rick Wolbertus[1], Renee Heller[1]
[1]*Amsterdam University of Applied Sciences, Faculty of Technology, Urban Technology, Energy & Innovation group, Weesperzijde 190, 1097 DZ, Amsterdam, The Netherlands*

[2]*Delft University of Technology, Faculty of Technology Policy and Management, Engineering Systems and Services, Energy & Industry group, Jaffalaan 5, 2628 BX, Delft, The Netherlands*

Summary

The COVID-19 lockdowns showed that working from home and conducting meetings online can change mobility patterns and needs substantially. This global pandemic may have also substantially changed mobility patterns on the long-term and therefore, also the need of electric vehicle charging infrastructure. Charging need dropped significantly but also changed the distribution of the load on the electricity grid throughout the day. This paper analyses changes in electric charging for different user groups during different phases of the pandemic to assess the long-term effects on EV charging needs.

Keywords: charging, EV, policy, case-study, deployment, energy consumption

1 Introduction

1.1 Background

COVID-19 lockdowns halted transport movements all across the world, electric vehicles were no exception. People were working from home more and contacted each other through digital means. Car related transport decreased by up to 50% in 2020 [1]. The use of electric vehicles in the Netherlands saw a similar drop. Many suggested that the effects of working from home would last longer than the COVID-19 lockdowns as the benefits of working from home, such as work effectiveness, decreased commute times, fewer traffic jams and cleaner air, were experienced at mass scale for the first time [2–4]. Major companies announced new working from home policies. Additionally, car transport shifted throughout the day as most only ventured out for necessary appointments.

These policies are also expected to affect the movements, and thus the charging needs, of electric vehicle drivers. This paper will inspect differences in charging behaviour before, during the COVID-19 lockdowns, with a special focus on curfews and user groups, and finally post-lockdown to see the long-term implications of new company policies. This is done by analysing a dataset on charging behaviour start 2020 up to and including March 2022. From this analysis, strategic effects on charging infrastructure planning are derived.

1.2 Literature

COVID-19 lockdowns disrupted the EV manufacturers supply chains, productions and operations [5]. Despite these disruptions, the full fleet of battery electric vehicles in the Netherlands grew 70% in 2020, compared to 2019 [6]. In 2020 as well as 2021, 1 out of 5 newly sold vehicles in the Netherlands was electric [7]. COVID-19 lockdowns affected different aspects of the energy system. For example, the roll-out of PV solar panels was much lower than predicted in 2020, because of manufacturing and supply chain issues, and decreased urgency because of lower peak demands during COVID-19 [8] . The effect of COVID-19 and related policies on the charging of electric vehicles has been monitored by various researchers. Two researchers monitored two charging points at a public facility in California, USA [9]. They found that charging sessions declined from the start of lockdown and came to a complete halt between August and half November 2020. The state of California then dealt with multiple issues such as increasing pandemic-related death rates, wildfires, and blackouts, explaining the lack of sessions. In the end of 2020, they monitored charging activity of roughly 25% of the original capacity (-75% decrease). The authors also found an increase in sessions from May 2021, which they assign to the roll-out of vaccines. Some researchers have also been monitoring pandemic EV charging in Utah [10]. Here, only a max decrease of -40% (60% of full capacity) was measured, with the steepest decline in May 2020. A group of Dutch researchers focused on three charging locations in the Dutch city of Utrecht [11]. They compared a residential area with an office area and an event location. During the first lockdown, they saw the most decline for the event location (-99.2%), after that, the office area (-89.6%), and the least decline was monitored at the residential area (-73.6%). Results from this study differ from the USA studies, since the first lockdown phase around March 2020 had the strongest effect (only 25% of full capacity, or -75% decline) whereas the later lockdown phases in 2020 led to a smaller decline.

These studies, although insightful, are based on a limited number of observations. The California study observed two charging points, and the Utah study used a few thousand observations for each phase. The Dutch (Utrecht) study used a larger set of charging points, but they were all located in the same city. In the upcoming analysis, we will also look at the different lockdown phases, type of areas and user segmentations. We will differentiate from other studies by using a national dataset containing at least four different large cities, as well as a few smaller municipalities, a larger number of observations, and with a special focus on curfews and different user segments.

2 Methods

2.1 Data

Charging data was collected from public charging stations in the Netherlands in the cities Amsterdam, Rotterdam, Utrecht and The Hague. In total more than 7.5 million charging sessions were collected from January 2020 up to March 2022. Background on the dataset and the data collection process can be found in another publication. [12]

Table 1: Data variables and examples

Variable	Example
RFID	60DF4D78
Address	Prinsengracht 767, Amsterdam
Start Connection Date Time	24-04-2015 13:56:00
End Connection Date Time	24-04-2015 17:14:00
Connection Time	2:18:00
Volume	6.73 kWh

2.2 Timeframes and comparisons

Lockdowns (work from home policies, closure of catering and entertainment industry and in some cases, closure of non-essential shops and gyms) were annotated in some of the graphs to illustrate their effects and the level of recovery after the lockdowns. We used the Coronavirus timeline of the Dutch government to compare important lockdown dates with our charging data[13]. The fuel comparison with kWh charged was scaled by the availability of traffic fuel (petrol) usage during COVID-19. The Dutch Central Bureau of Statistics keeps track of traffic, fuel, behaviour and car ownership, among others. This data was available on a monthly basis until April 2021. Energy (kWh) charged was summed with all the charging points that were available at January 2020 to avoid measuring increased roll-out and adoption. Office comparisons were made by selecting public charging points from office areas and by fingerprinting sessions which behaviour corresponded with employee charging behaviour. A night curfew was installed to combat the spread of the new variants of COVID-19. The curfew was first installed in January 2021 and was extended until end of April 2021. The curfew had two distinct phases with two different end times. We selected data from these periods in time and compared them with other months during lockdown. Data was analyzed using Rstudio.

3 Results

3.1 COVID-19 impact analysis

COVID-19 lockdowns saw an immediate impact on the charging behaviour once installed with a 50% reduction in charging sessions and energy charged. At the same time average connection time at the charging station increases with over 50% as EV drivers left their car at the charging station during the early days of the lockdown. After restrictions were lifted in early June 2020 it still took a while before at the least the same number of users were reached (partly also due to underlying growth in the number of electric vehicles).

The second lockdown in the fall of 2020 had a far lesser impact on charging behaviour. It was only in late January 2021 when curfews were installed that the number of charging sessions per charging station dropped again. Still a significant reduction in the number of charging sessions per station could be observed compared to February 2020. It is not until March 2022 when all restrictions were lifted that charging station use, both in terms of sessions per station and average connection time, were similar to pre-COVID.

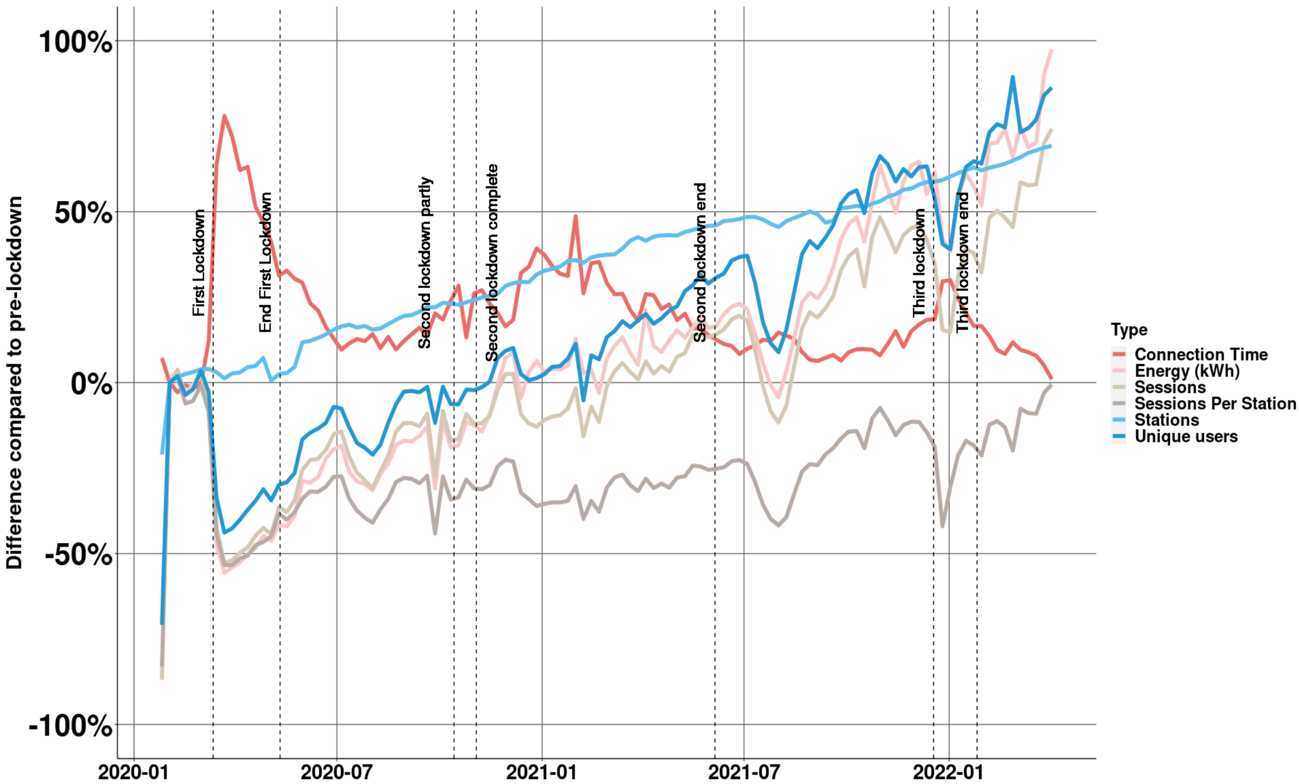

Figure 1: Coronavirus effect on charging behaviour over time

Given that the number of charging sessions per station and connection have returned to pre-COVID levels, the question arises if a significant long-term effect could be expected of the coronavirus on car related transport behaviour and consequently charging behaviour. For further inspection charging behaviour across the day for different phases in the coronavirus era are inspected. What stands out that there is a significant reduction in evening demand compared to pre-lockdown behaviour. Work demand seems to be returned to pre-COVID levels (see significant reduction in first lockdown) but charging session starts seemed to be shifted across the day away from classical 9-to-5 office behaviour. March and April 2022 show a slight increase in the evening peak, but not as strong as in the morning. Such results might indicate more flexible working hours or hybrid working environments. Such a shift in charging behaviour away from the peak might also be good news for grid operators as local power demand is shifted towards the day (coinciding with solar production) and away from peak hours.

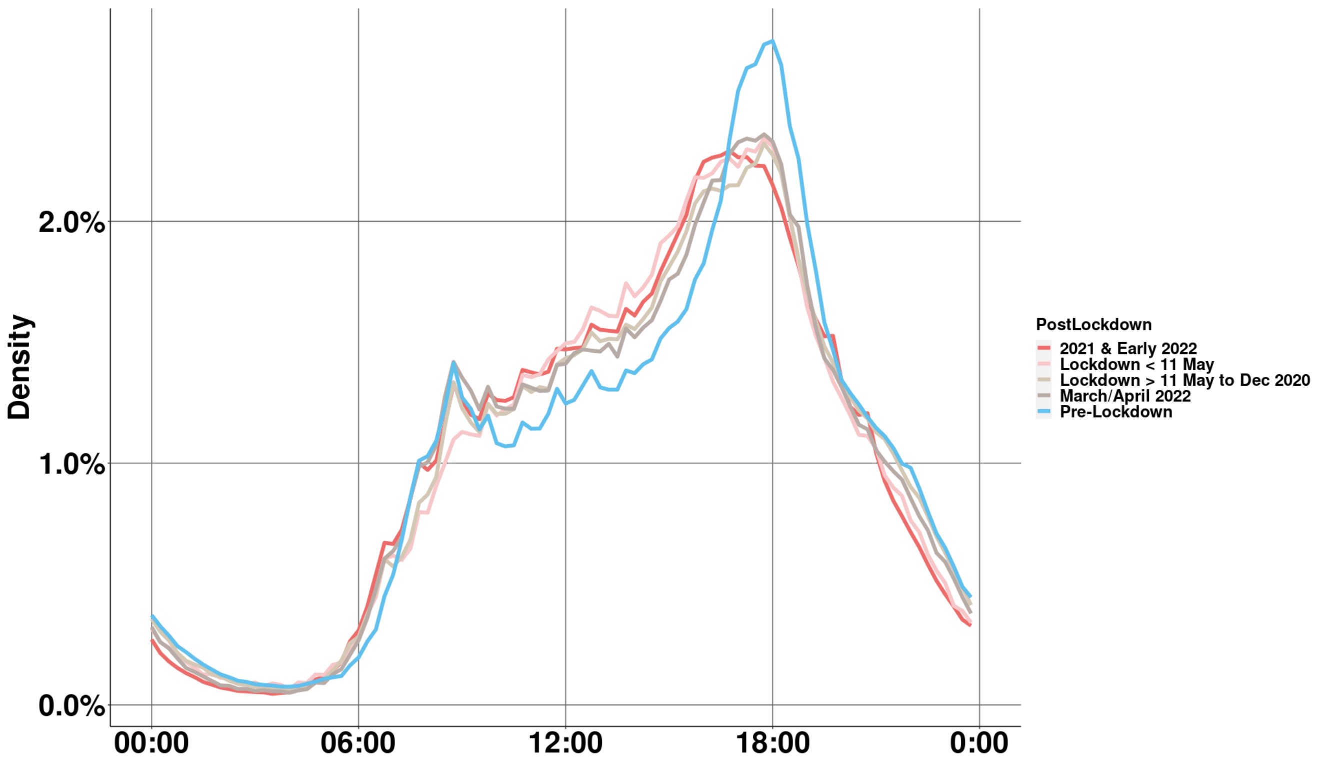

Figure 2: Density plot for charging session start across the day for different phases in 2020-2022

Additional insights are gained by comparing users that were already charging in January 2020 and still are in 2022. For this analysis users that charged at least 5 times in January 2020 and were still charging in March 2022 are included. Analysis excludes user groups such as taxis and shared vehicles. A total of 586 users (19550 charging sessions) were included in the analysis. Results of this comparison are shown in Table 2 for different metrics.

Table 2: Comparison between January 2020 & March 2022 for EV drivers active in both months

Date	**Sessions/user**	**Energy/ Session (kWh)**	**Connection Time**	**Unique number of charging stations/user**	**Sum of Energy charged (kWh)**	**Number of unique neighbourhoods visited**
January 2020	14.9	16.5	12.7	3.2	221	1.94
March 2022	10.9	17.0	11.9	2.6	159	1.58

Although some metrics have stayed nearly the same (Energy per session and Connection Time), it can also be seen that the same drivers have been charging much less, both in terms of the number of charging sessions and total energy in a single month. Although the turnover per charging stations has come close to near normal in March 2022, EV drivers individually still drive less. This can also be seen from the number of unique charging stations they visited and as well different neighbourhoods and or cities. Most charging tends to be done at a few charging stations. These results could show indications of lasting effects of new COVID-19 travelling habits among EV drivers as a possible result of a shift in workplace norms.

3.2 Fuel comparison

COVID-19 has led to a decrease in mobility activities during 2020 and 2021. We compared this decrease of energy charged with the decrease of (traffic) petrol sales using CBS data [14]. The comparison point was set at January 2020. The data was aggregated to monthly data between January 2020 and April 2021. Only charging points that were in the system from January 2020 were used in the analysis, to avoid adoption growth effects. In April 2021, 97% of these locations were still active, indicating a maximum potential loss of 3% of locations or location charging data.

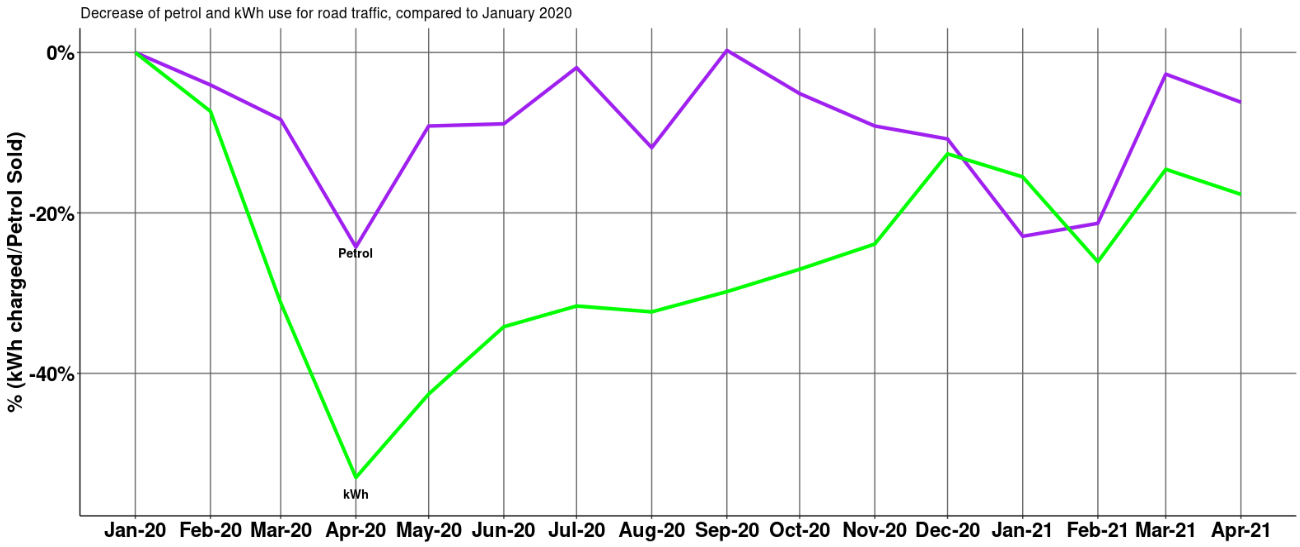

Figure 3: Comparison of national traffic petrol sales (purple) with kWh charged in G4 municipalities (green) in 2020 [14]

Figure 3 shows the differences in decrease of petrol and electricity sales for vehicles after January 2020 until April 2021. Both lines show a strong decrease around the first lockdown at the end of March in 2020. The underlying data reveals that in March, petrol sales decreased with almost 10% whereas kWh charged decreased ~30%. In April, decrease was the strongest, with a ~25% decrease in traffic petrol sales and ~50% decrease in kWh charged. This decrease recovers partially during the summer, and in September 2020, petrol sales were even slightly higher than in January 2020. Both lines also show a dip (extra decrease) of petrol and kWh charged during curfews, where the initial effect seems stronger for petrol sales, but recovers faster.

The much higher reduction in electricity sales compared to petrol can be explained by the different user groups. As electric transport is mostly centred around passenger cars, with only a few trucks on the road, gasoline and diesel vehicles are present in all sectors. Goods transports barely were reduced during lockdowns hence explaining the difference between the two. Overall reduction in 2020 (compared to 2019) was ~20% for passenger cars (24% for business related travel) and only 3% for good related transport[15].

3.3 User group comparison

EV charging had a much stronger decrease during initial lockdown (March-April 2020) than petrol vehicles. A potential contributing factor to this effect (aside from transport) could be business related. Considering the entire personal vehicle fleet in the Netherlands in 2020, only 17,3% is categorized as business (company car, business lease, or personal lease) [16]. However, this number is much higher for electric vehicles. Additional CBS and RDW data reveals that in 2020, only roughly a third of the electric vehicles on the Dutch road was owned personally. For full electric vehicles, only 21% was personally owned.

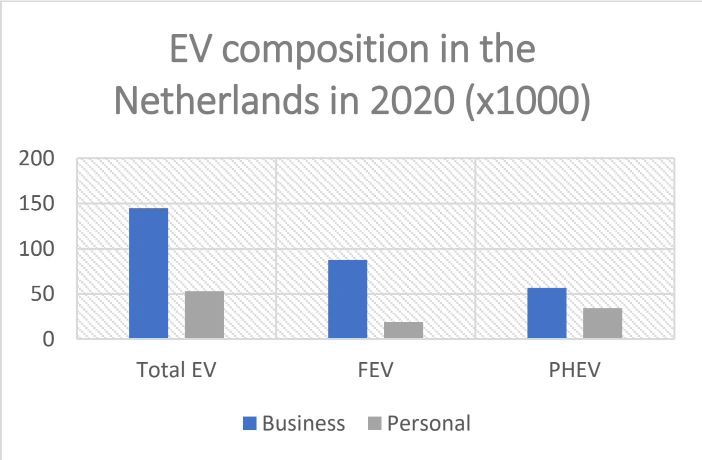

Figure 4: EV owner composition in the Netherlands in 2020 [17]

Charging behaviour of professional user groups are analysed to determine how these groups were affected during COVID-19 and compared them to the full set containing all public charging. Decrease rates were calculated using the initial charging numbers for each group in January 2020 (this is the 0% point in the graphs). The following sections will discuss charging during COVID-19 for office areas, employees/commuters, taxi drivers and shared vehicles.

Office Comparison

A potential explanation for the stronger initial lockdown decrease in kWh charged is the low percentage of personal vehicle owners in the EV fleet. Most electric vehicles are business owned and/or on a car lease contract. This implies that the vehicle has an important function in either commuting to work, business-related travel, or traffic-related services. Some lockdowns included a work from home policy, either mandated or highly advised, which affected the number of commuters on the road. Working from home was still recommended at times when leisure activities were allowed again. The following paragraphs will address office charging, using three groups to compare (see Table 3).

Table 3: Parameters of Office comparison groups

Comparison group	**Parameters**
All sessions (full set)	All public charging data
Sloterdijk Office Area	All charging from 17 charging points in an office location
Suspected employees (office/commuters)	All charging sessions during weekdays (mon-fr), starting between 7-10AM and connected between 3-10 hours

17 charging points that were in Sloterdijk Office Area ('Bedrijventerrein i') are analysed and compared them with all public EV charging, in 2020, as well as 2021. The full set of sessions and the office area sessions with the sessions of individual users that are identified as employees are compared. We assumed the following while identifying potential employees on the public charging network: Employees start their charging session on weekdays between 7 and 10AM, and their connection time is between 3 and 10 hours. We found that 7-8% of the sessions corresponded with this behaviour.

In 2020, we see a steep decline of kWh charged for all groups in March-April 2020 (see Figure 5). This is when the COVID-19 lockdowns started in the Netherlands. Office area charging points were affected, even more so than the full set of sessions. The energy charged at the office decreased with 70%. The green and pink lines (all sessions and suspected employees) do not decrease as strongly and recover more quickly than the blue line (charging points in Sloterdijk I office area). The 7-8% of sessions that we suspect are employees, showed similar decreases to the full set of sessions, and recovers more quickly than both groups towards the end of 2020.

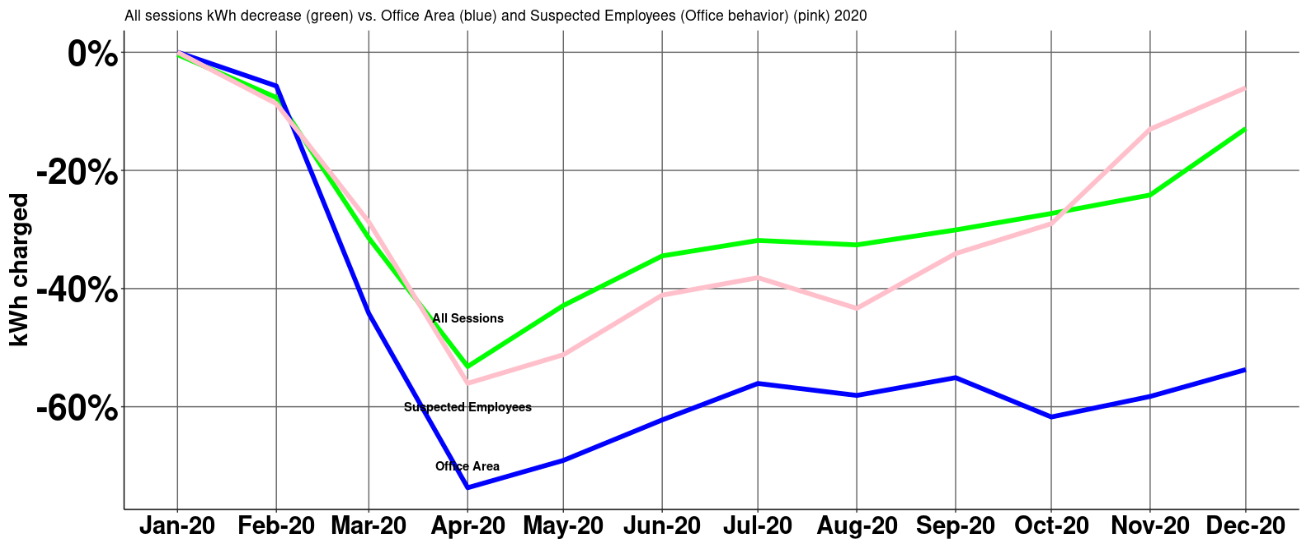

Figure 5: Comparing the full set of sessions (green line) with the sessions in Sloterdijk office area (blue line) and the sessions with behaviour that is associated with employees (pink) in 2020. kWh decrease is based on the kWh charged that was observed for each group in January 2020.

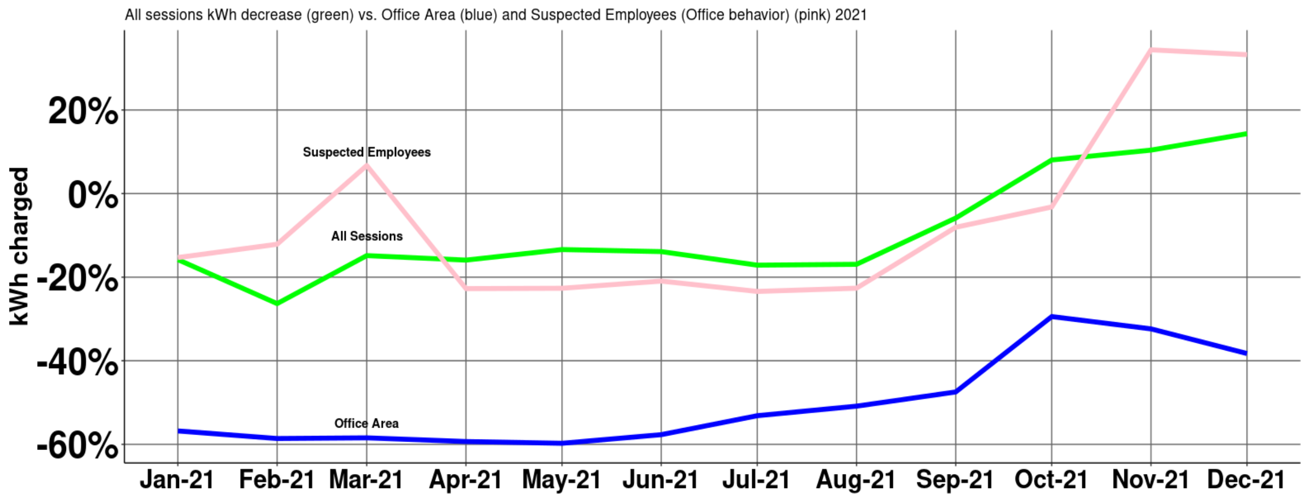

Figure 6: Comparing the full set of sessions (green line) with the sessions in Sloterdijk office area (blue line) and the sessions with behaviour that is associated with employees (pink) in 2020. kWh decrease is based on the kWh charged that was observed for each group in January 2020.

Charging at the office area did recover slightly by fall 2021 (see Figure 6). Suspected employees charged more during early 2021 than before, and the demand of this group experienced a steeper growth in the end of 2021.The green line (full kWh charging) and the pink line (suspected employees) exceed 100% in 2021, despite our efforts to select only locations that were available from January 2020 on. We looked at January and June for each year to account for potential EV adoption growth effects (Table 4). Table 4 shows that the number of unique active RFIDs increased in 2021, while the number of active locations slightly decreased and the number of RFIDs divided by the number of locations grew significantly. This has led to an increase of kWh demand despite a lower number of active monitored charging points. This effect can be prescribed to many factors, such as increased electric vehicle adoption and an increase of commuters after work from home policies were temporarily relieved.

Table 4: Number of active charging points and users (filtered on CPs that were available from 1-2020)

Point in time	**# unique RFIDs (1 month)**	**# unique Locations (filtered, 1 month)**	**RFIDs / Locations (rounded)**
January 2020	61866	7730	8
June 2020	45460	7502	6.06
January 2021*	59092	7490	7.89

June 2021	71925	7509	9.58
January 2022	85344	7326	11.65

(*the number of RFIDs was higher in December 2020 than January/February 2021, policy may have played a role)

Shared vehicles and Taxi drivers

We were able to distinguish a group of shared vehicles (185 unique RFIDs, minimum per month active was 175) and a group of Amsterdam taxi drivers (630 unique RFIDs, minimum per month active was 603). These groups also show a similar dip during the first lockdown (see Figure 7), with taxi drivers having the most extreme kWh decrease of 80% compared to January 2020. Charging of taxi drivers find some momentum again during summer, where some policies were temporarily lifted and the catering industry opened up. In 2021 and 2022 the number of identified RFIDs drops significantly, to 2/3th and 1/6th of their original number, or lower. Potential explanations include takeovers, drivers who are out of business, and replaced cards. However, this drop is too significant to confidently represent the segments after 2020, therefore, we chose not to include user segment analysis over a longer time period.

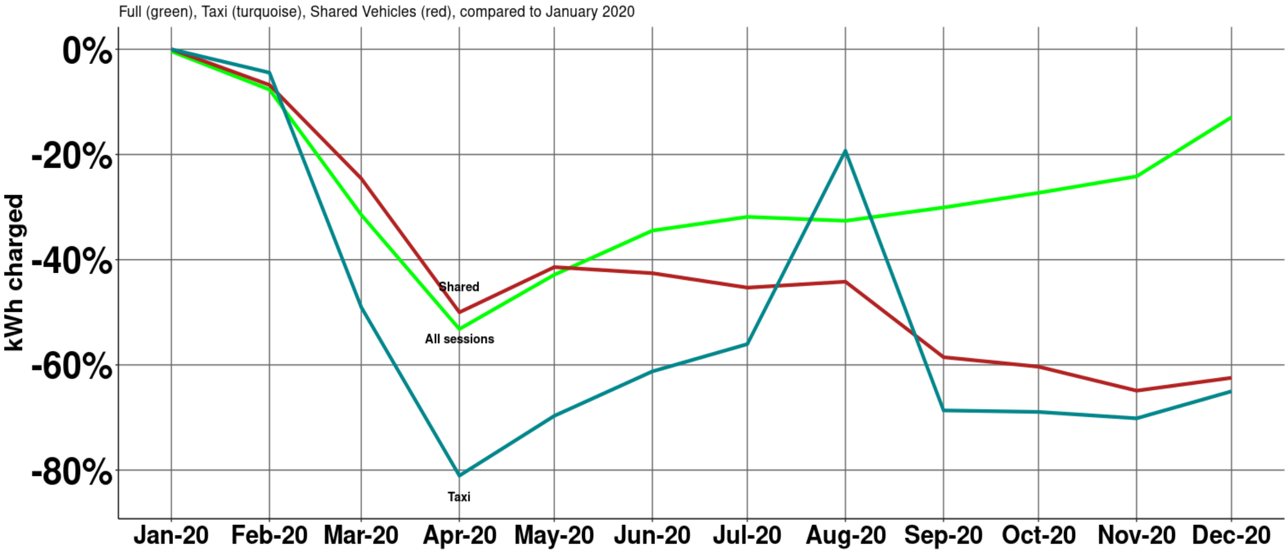

Figure 7: User segments and decrease of kWh charged during COVID-19 lockdowns in 2020. The kWh decrease is determined by comparing the kWh charged of each group with their kWh charged in January 2020.

3.4 Curfew analysis (2021)

A curfew was installed to combat the spread of the new variants of COVID-19. The curfew was first installed on January 23, 2021. Curfew times took place between 9PM (21:00) and 4:30AM (4:30). On March 31, 2021, the curfew was extended with a delayed start time of 10PM (22:00). The curfew took place until April 28, 2021 [13]. For this analysis, we compared the kWh charged between 6PM and 11PM over four periods in time: the month before the curfew, the 9PM curfew, the 10PM curfew and the month after curfew. Details can be found in the table below (Table 5).

Table 5: Summary statistics of sessions started in the evening during Curfew phases

Summary Statistics	**Before Curfew** *~1.5 month sample*	**First Curfew** *~ 2 month sample*	**Second Curfew** *~1 month sample*	**After Curfew** *~1 month sample*
Sample size (# of sessions)	700,633	910,988	314,976	340,565
# of sessions that started between 7PM – 8PM	37,477	70,828	23,453	20,207
Percentage	**5.3%**	**7.8%**	**7.4%**	**5.9%**
# of sessions that started between 8PM – 9PM	30,052	40,526	16,958	15,283
Percentage	**4,3%**	**4,5%**	**5,4%**	**4.5%**
# of sessions after 9PM	54,530	22,828	25,153	22,646

Percentage	**7,8 %**	**2,5%**	**7,9%**	**6.6%**
# of sessions that started between 9PM-10PM	24,660	13,786	11,361	11,046
Percentage	**3.5%**	**1.5%**	**3.6%**	**3.2%**

Outside of curfews, the percentage of sessions that start between 7PM and 8PM is between 5.3% (before curfew measurement) and 5.9% (after curfew measurement). During both curfews, this percentage increased to 7.8% (during the 9PM curfew) and 7.4% (during the 10PM curfew). Before curfew, the percentage of all sessions that started after 9PM was 7.8%. During the first curfew, this number dropped to 2.5%. During the second curfew, this percentage recovered to 7.9%, almost identical to the before curfew measurement. The percentage of sessions that started exactly between 9PM and 10PM was also almost identical between the second curfew (3.6%) and the before curfew measurement (3.5%). We observed no late-evening decline during the second curfew, as opposed to the first curfew.

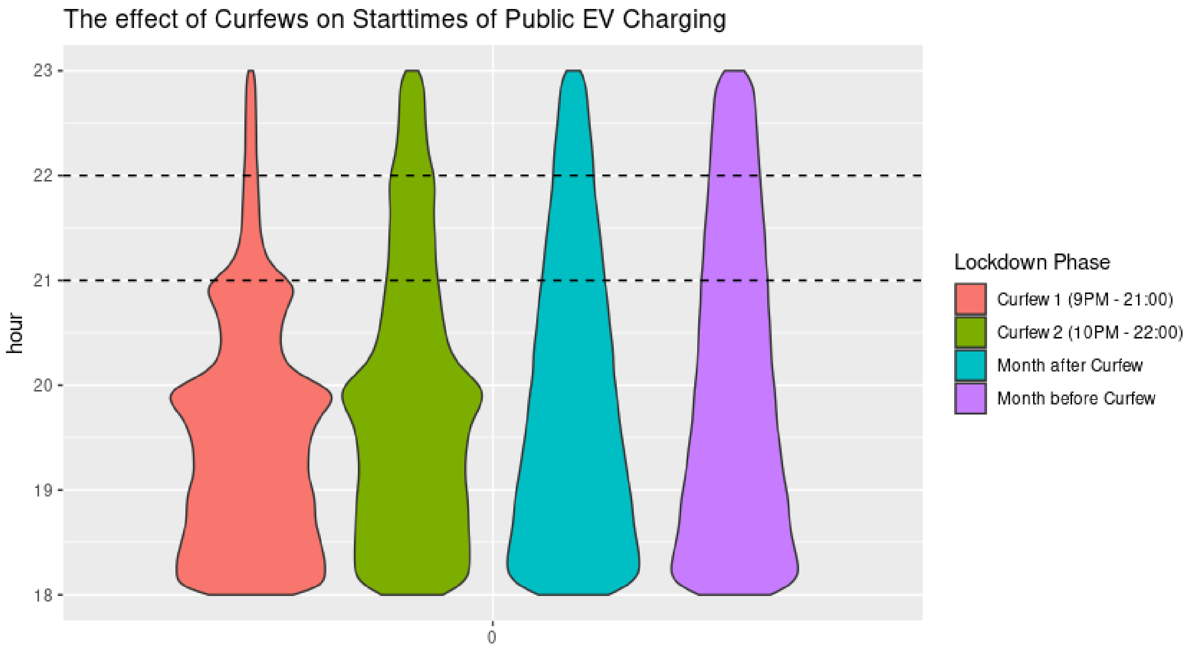

Figure 8: Violin plot illustrating the differences in start time distribution between 6PM-11PM
From left to right: Curfew 1, Curfew 2, Month after, Month before

The violin plot (Figure 8) illustrates how curfews affected the start times of public EV charging during lockdown. The month before and after the curfew are almost identical in shape, whereas the shape of the two curfew periods differed. The first curfew period differs strongly and on multiple instances in the evening. The second curfew illustrates the same 8PM spike as the first curfew, but later in the evening the shape becomes more similar to the periods before and after the curfew.

4 Conclusion & Discussion

4.1 The overall impact of COVID-19 lockdown policies on EV charging

COVID-19 lockdowns had a significant effect on travel demand and therefore EV charging demand. Initial lockdowns brought the world to a standstill with a reduction of more than 50% in the energy that was charged at public charging stations in The Netherlands. This resulted in much longer connection times at charging stations as most stayed at home. 2020 saw a slow recovery in the number of charging sessions and energy charged but this was mainly fuelled by a large number of new EVs coming to the market. It was only until March 2022 that the energy transferred at charging stations was comparable to pre-COVID levels.

In general, electric mobility was more heavily reduced than vehicles driven by petrol as most applications of electric mobility are still in personal vehicles. In the Netherlands most EVs are also company lease cars from which it can be expected that these drivers mostly work at offices for whom it is easier to work from home than other professions. As well, logistics, which continued nearly fully operational during the lockdowns, has nearly not been electrified. Therefore, petrol sales did not fall to levels as could be seen with EV charging.

4.2 Demand migration

Overall, the demand migration caused by COVID-19 reduced the 6PM charging peak (see Figure 2). The effect is still at play, 2 months after all restrictions were lifted. This capacity reduction occurs at a moment other electricity use of households peaks, so this reduction helps to keep grid capacity growth at lower levels than before COVID-19. Of course, for real grid capacity expansion, a local grid investigation is needed, but this analysis gives a first indication of possible lower capacity needs.

Curfews affected demand differently (see Figure 8). Both curfews temporarily increased the number of sessions that started between 7PM and 8PM with more than 2%. This demand migration towards 7PM-8PM, could have created issues in a larger user pool, since this increase in demand does happen during a peak consumption window. During the first (9PM) curfew, the number of sessions that started at 9PM dropped with 5%, and the number of sessions between 9PM and 10PM also dropped with 2%. During the second (10PM) curfew, we saw another 1% increase of sessions between 8PM and 9PM, compared to other periods, but we didn't observe the 5% decrease of all sessions that started after 9PM. In fact, in the later evening, the second curfew resembled the period before the curfews, indicating that the second curfew had little effect on late night charging and demand in the late night was not migrated as much as during the first curfew.

4.3 Policy sensitivity differences between user segments

Lockdown and work from home policies affected energy use in all traffic, but more so (overall) in electric vehicles than in petrol vehicles. A potential explanation was the majority of EV adoption being business-related. The impact was most visible in April 2020, where the consumption was drastically lowered, especially for taxi drivers, and in the measured office area. The electricity demand for public charging in an office area was much lower than the already reduced demand of public EV charging altogether, although the demand that is associated with suspected employee charging did not differ as much from normal charging. The effects on charging of commercial vehicles differed. Although taxi drivers were affected the most, the initial impact for shared vehicles did not differ much from the full user group. In late 2020, differences started to arise, with the full group of sessions recovering from initial effects whereas kWh consumption for shared vehicles lowers even more.

Dutch media and local governments have also reported the challenges of taxi drivers (including non-electric taxi drivers). TaxiPro, the Dutch trade magazine of the taxi sector, reported a 90% loss of work in 2020 [18]. This is more extreme than the -80% we have measured for electric taxi drivers who are active in the urban agglomeration of the Netherlands. The municipality of Amsterdam monitored their taxi sector in 2020 and they found similar patterns as our sample of electric taxi drivers: an average of 77% decrease at the first lockdown, and a recovery during the summer months [19]. Dutch Royal Traffic reported that 30% of the taxi drivers that were active in early 2020 had quit their job by summer 2020 [20]. The municipality of Amsterdam also reported in their monitor that, despite loss of taxi drivers and a shrinking sector, the percentage of electric taxi drivers did not change much. Based on these comparisons, we can conclude that electric taxi drivers in the urban agglomeration were slightly less (but still strongly) affected by COVID-19 lockdowns than the taxi sector altogether, and that the percentage of EV adoption among taxi drivers was not negatively affected by the lockdowns. The taxi sector did have great challenges in overcoming their negative lockdown effects, and it might take a long time for this whole sector to recover, be it electric or non-electric.

4.4 Long term effects

Analysis of charging patterns from early 2022, when nearly all restrictions were lifted show that there could be some long-lasting effects of the COVID period. A clear shift in the timing of charging sessions in the evening could be observed, indicating that strict 9-to-5 workplace norms are no longer in place. This does not necessarily have an impact on the number of charging stations but could result in a shift in local energy demand (away from a peak) and could result in longer connection times (earlier start, but same end time). This increases the potential for smart charging electric vehicles at these stations. Comparison of a group of EV drivers active before and after COVID restrictions showed that this group charged significantly less (up to 30%) and charged at fewer different locations. A possible explanation is that business related travel is reduced as there is a substantial shift to online meetings. Comparison of office areas compared to the general population also showed a significant reduction. Further research is needed to determine how long-lasting effect this effect will be and to which extent this reduces the need for business- and visitor-related charging. This could also impact the need for fast charging along highways, a sub-section of charging stations that was not included in this paper.

4.5 Limitations

EV adoption is growing steadily in the Netherlands. It is challenging to determine the demand reduction long-term, since the fleet is growing, and resources are shared between more users over time. This made policy sensitivity analysis more difficult for late 2021: it cannot always be said which portion of the demand increasing again can be attributed to lifted restrictions, and which portion should be attributed to growth of the user base (see Table 4). Another issue is the long-term availability of charging points. Some of the charging points (see Table 4) were not used every month, and it is not possible from our data to determine if this is because of user preference, or for example technical- or construction issues that temporarily prevented users from accessing these charging points altogether. In case of the latter, some users may have opted for a charging point that was installed after the January 2020 baseline period and therefore, these sessions were not included in our data analysis. Suspected employees were recognized through an assumption, therefore it is possible that this group contains some sessions that coincidentally were made under the same behaviour by non-employees.

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Authors

Mylène van der Koogh is a researcher at the Amsterdam University of Applied Sciences and a PhD student at the Delft University of Technology. Her topics of interest include public charging infrastructure and the impact of policies on urban (electric) mobility.

Rick Wolbertus is a researcher at Amsterdam University of Applied Sciences (AUAS). He holds a PhD on charging behaviour of electric vehicles. His research topics are charging behaviour, the effect on the electricity grid, and the effect of charging infrastructure on EV sales. He leads the four-year Future Charging research project.

Renée Heller is professor Energy & Innovation at the Amsterdam University of Applied Sciences. She holds a PhD from Utrecht University and has been involved in numerous projects in the field of sustainable energy. Her group is involved in many projects around electric mobility and grid integration.