Charging free floating shared cars in metropolitan areas

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Abstract

This paper analyses the effect of two new developments: electrification and 'free floating' car sharing and their impact on public space. Contrary to station based shared cars, free floating cars do not have dedicated parking or charging stations. They therefore park at public parking spots and utilize public charging stations. A proper network of public charging stations is therefore required in order to keep the free floating fleet up and running. As more municipalities are considering the introduction of an electric free floating car sharing system, the outline of such a public charging network becomes a critical piece of information. The objective of this paper is to create insights that can optimize charging infrastructure for free floating shared cars, by presenting three analyses. First, a business area analysis shows an insight into which business areas are of interest to such a system. Secondly, the parking and charging behaviour of the vehicles is further examined. The third option looks deeper into the locations and their success factors. Finally, the results of the analysis of the city of Amsterdam are used to model the city of The Hague and the impact that a free floating electric car sharing system might have on the city and which areas are the white spots that need to be filled in.

1 Introduction

In the past years car sharing has gained momentum and has increasingly become an innovative solution for personal mobility. Instead of an individual owning one or multiple vehicles a fleet of vehicles is shared between multiple users throughout the day. A shared car is often complimentary to other modalities and provides a solution for sporadic car usage [1]. Simultaneously, cities often embrace car sharing as there are multiple possible advantages to car sharing including less cars on the street, less kilometres driven, less air pollution and lower costs for users [2].

Car sharing exists in multiple forms and systems. A Free Floating Car sharing system (FFCS) is considered the most flexible of all. Many car sharing systems rely on bringing back the car to its original place or at least a set of selected stations. Members of a FFCS can pick up any car in the fleet at any point and leave it at any point. The only limits are often within a certain geographical boundary, (part of a) city, and that the car is parked at a public parking spot. The rent starts when the car is picked up and ends when the car is left behind. Employees of the fleet owner relocate the car, clean it and fill it up or charges it if necessary. As electric cars are increasingly the mode of choice for these systems, resulting in a Free Floating Electric Car sharing System (FFECS), a new issue is at rise. Electric cars need to charge and as the system is free floating, an extensive charging network is required. A reliable charging network is considered one of the key aspects according to Car2Go, one of the largest free floating shared electric vehicle operators [3]. While origins and destinations of free floating car sharing vehicles are significantly different from regular electric vehicle users, leading to different charging needs than currently considered. Hence a mismatch between current charging infrastructure availability and charging needs by car sharing vehicles is likely to occur. To name one, car sharing schemes are most likely used as a last mile solution leading to more charging needs close to public transport hotspots.

This research examines the optimal locations for charge points in urban areas and provide key indicators for cities on the facilitation of an FFESC in their city. The research is executed by examining a three level study towards charging and parking patterns in the Dutch city of Amsterdam. A business area analysis compares the most suitable neighbourhoods for such a system. The usage study examines the number of trips per neighbourhood, the required amount of charging infrastructure for FFECS vehicles in Amsterdam and examines hot spots in the city. Finally a charging station location study examines the most suitable locations for charge points. It compares usage of charge points on major roads to inner neighbourhood charge points and charging plazas (combinations of charge points on a single location). Finally the study uses the lessons learned to design the best possible charging network for an FFESC system in the Dutch city of The Hague.

2 Previous Literature

Usage of FFECS systems is not homogenous throughout cities and land use functionality (living, working, visiting) strongly influences the usage patterns [4]. Simultaneously, the adoption of car sharing also depends on personal characteristics and attitudes. The literature has provided a vast amount of possible indicators. Age appears to be of influence. As young people do not have the money and/or need to own a car they tend to be likely to adapt to car sharing. Therefore the age group 18 to 40 seems to be most likely to adapt [5,6,7,8]. Once, adopted they tend to postpone or waive the purchase of new vehicles and remain a shared vehicle user. As it is easier to postpone the purchase of a vehicle than to cancel it, car ownership provides a good indicator of the likeliness a neighbourhood is interesting for shared vehicle operators [7,9,10]. Previous research has also revealed that car sharing is most interesting for people with high levels of income [5,6,11] and high levels of education [6,7,8] and the number of expats in an area [12]. One of the most fundamental regarding economic viability of a FFECS system which is population density [8,11,12]. For a system to be fully operational it needs to provide people with enough options that they have a vehicle available whenever they require one. For such a dense system to be economically viable a significant number of users need to live, work and/or recreate in the operator’s business area. Finally, vehicles also need to be left somewhere and therefore offices and recreational activities [6,11,13] are also expected to have a positive impact on usage levels. Finally, as FFECS systems are expected to be a back up to public transport users the level of public transport seems to have a positive impact on shared vehicle usage [8,10].

Although literature is growing on success- and failure factors of FFCS, there is still limited research on the particular charging demands from FFECS. In particular in-depth analyses of utilization of charging infrastructure by FFECS in cities is lacking. This study will use detailed data records of a FFECS system in the Netherlands to analyse charging behaviour of these vehicles in order to evaluate the particular usage patterns and requirements of charging infrastructure.

3 Methodology and Data

The methodology requires three stages in which it compares the heterogeneity of FFECS systems in different neighbourhoods and utilised charging stations. Firstly, using CBS Statline [14], the neighbourhoods of Amsterdam are categorised along a variety of variables:

- Number of employees
- % of people in age group 15-24/ number of people in age group 15-24
- % of people in age group 25-44/ number of people in age group 25-44
- Average income

- Housing value
- Automobile ownership per household
- People density
- % Expats
- Number of bus/tram stations
- Number of metro stations
- Number of train stations
- Surface area of shops (m2)

Apart from the variables described above we have implemented number of employees and housing value. Due to the lack of data we were not able to implement levels of education. Note that the literature often analysed individual users where this research focuses on the neighbourhood levels.

Using a multiple regression analysis we identify the variables that determine what variables determine the neighbourhoods that are incorporated in the FFECS business area. Secondly, using a multiple regression analysis we analyse the usage of the system. We determine the number of rides that started and ended in different neighbourhoods. We also focus on the percentage of rides that end at chargers and if we can determine any heterogeneity amongst neighbourhoods. Thirdly, we determine the best locations for charging stations regarding specific locations. We analyse the FFECS sessions at chargers on major roads, near train stations or so-called charging plazas where multiple chargers are located in close proximity to each other. Finally, we plot our results on the city of The Hague and determine the neighbourhoods where more charging infrastructure is needed.

For the data we use a variety of sources. Firstly, the parking data of a large FFECS in Amsterdam has been acquired. This dataset provides location, battery level and if the vehicle is charging every 15 minutes if the vehicle is available for hiring. Period,

Secondly, we are taking data from the Statline database of the Central Bureau of Statistics (CBS) [14] and the municipality of Amsterdam [15]

4. Results

4.1 Business area

In order to explore the types of neighbourhoods that are connected to the car sharing system we have executed a multiple regression analysis of the neighbourhoods involved and compared them to the neighbourhoods not involved. See figure 1.

The neighbourhoods that appear to be interesting have a relatively high number of people between 18 and 45 which is the age group where car ownership is still relatively low and instead of purchasing a vehicle people opt for a car sharing system and therefore appear to be postponing or even avoiding a private vehicle purchase. Neighbourhoods with a high population density, low car ownership, relative high income and proximity of railway stations also appear to be interesting which is in line with findings in available literature. The negative correlation with bus/tram stops is contrary to the idea that FFECS is a back-up for those that use public transport on a daily basis. A more likely explanation however might be the high percentage of cyclists in the city of Amsterdam that use FFECS as a backup for their bicycle rides. As bicycle ownership was not taken into account we cannot verify this. The number of expats, metro stations and number of employees appear to have no significant influence.

The model is limited due to the analysis of only the city of Amsterdam and some covariance between the variables but shows (with an adj. R^2 of 59%) a good insight into the attractiveness of several areas.

Meervoudige correlatiecoëfficiënt R	76%							
R-kwadraat	57%							
Aangepaste kleinste kwadraat	56%							
Standaardfout	0,29329227							
Waarnemingen	395							
Variantie-analyse								
	Vrijheidsgraden	*Kwadratensom*	*Gemiddelde kwadraten*	*F*	*Significantie F*			
Regressie	11	44,40524177	4,036840161	46,92889412	3,30434E-64			
Storing	383	32,9457962	0,086020356					
Totaal	394	77,35103797						
	Coëfficiënten	*Standaardfout*	*T- statistische gegevens*	*P-waarde*	*Laagste 95%*	*Hoogste 95%*	*Laagste 095%*	*Hoogste 095%*
Snijpunt	0,093888741	0,115799994	0,810783639	0,417993454	-0,133794567	0,321572048	-0,133794567	0,321572048
p_15_24_jr	0,003494818	0,001787558	1,955079725	0,051300623	-1,98374E-05	0,007009473	-1,98374E-05	0,007009473
p_25_44_jr	0,006588744	0,001903869	3,460712482	0,000599431	0,0028454	0,010332088	0,0028454	0,010332088
bev_dichth	7,29105E-06	2,40428E-06	3,032525725	0,002590269	2,56381E-06	1,20183E-05	2,56381E-06	1,20183E-05
p_west_al	0,001239758	0,003105209	0,399251083	0,689930735	-0,004865633	0,00734515	-0,004865633	0,00734515
auto_hh	-1,088646512	0,108149321	-10,06614285	2,65502E-21	-1,301287239	-0,876005784	-1,301287239	-0,876005784
woz	-0,001502678	0,000593181	-2,533255482	0,011699016	-0,002668976	-0,00033638	-0,002668976	-0,00033638
ink_ontv	0,038533103	0,006588653	5,848403903	1,06472E-08	0,025578644	0,051487562	0,025578644	0,051487562
treinstations_500m	0,126285885	0,044203264	2,856935751	0,004510832	0,039374436	0,213197334	0,039374436	0,213197334
bus_tram_haltes_500m	-0,004703117	0,001720655	-2,733329087	0,006560514	-0,008086231	-0,001320004	-0,008086231	-0,001320004
metro_haltes_500m	-0,001525361	0,009743842	-0,156546201	0,875684989	-0,020683481	0,017632758	-0,020683481	0,017632758
werkzame personen per ha land	0,000108147	0,00024113	0,448501977	0,654044587	-0,000365957	0,000582251	-0,000365957	0,000582251

Table 1Multiple regression analysis of neighbourhood attractiveness for business area.

4.2 Usage

The usage-analysis focuses on the actual usage of the free floating car sharing system and the charging characteristics. We focus on the number of transactions that end, their locations, battery levels and if they decide to leave the car at a charging station or not. We firstly focus on the question if people decide to charge the car and to what extent the battery level plays a role. The first thing that we notice is that most of the transactions do not involve a charging station. Of all 61.000 transactions that were included in this analyses over the period 92 days, only 11.2% end at a charging station. This is due to the fact that most trips are relatively short and therefore the battery levels are still at an 'acceptable' level. The second reason might be that those that use the vehicle are often not the person that has to use the vehicle next. Therefore they do not have an incentive to leave the vehicle to charge fully. When we analyse the starting battery levels for the charging sessions (fig. 1) we notice two things: Firstly, the battery levels appear to only have a significant impact when they are below 20% or 30%. This is due to the fact that vehicles cannot be left unplugged when batteries are below 20% and users get beneficial driving minutes when levels are at 30%. The second peak is at 80% and the authors could not find a possible explanation for this.

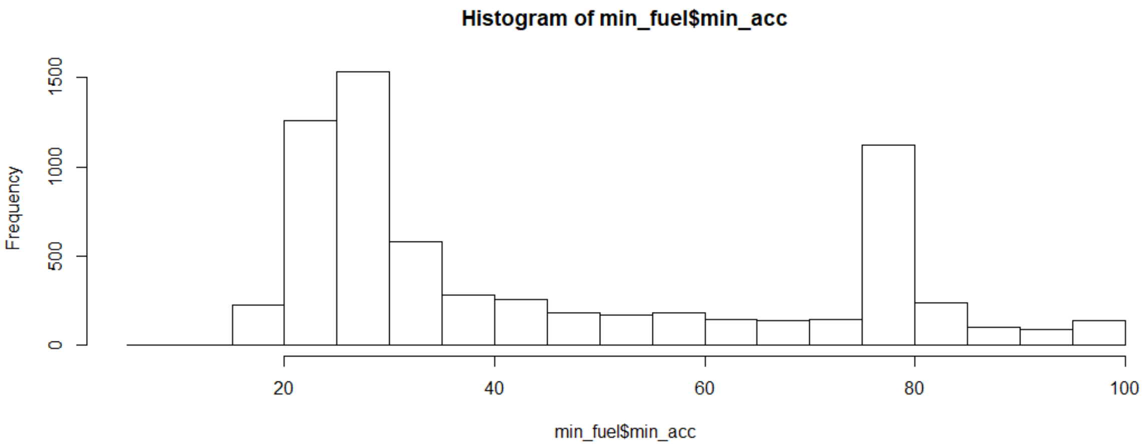

fig. 1 Histogram of starting battery level when transaction is ended at a charging station

When analysing the areas that vehicles are left and picked up a few things are noticed (fig. 3). The first notable issue is the non-significant negative coefficient that population density has on the number of transactions in a neighbourhood. However, the number of people under 45 has a significant positive effect which implies that the age group is a more important factor to the number of transactions than a generally populous neighbourhood. The second thing that can be drawn from the analysis is the positive relationship between vehicle ownership and usage of shared electric vehicles, which is contrary to the previous analysis. This might be due to the fact that areas with low vehicle ownership are more interesting to implement in the system, but that the usage of the system is higher in areas where cars are a preferred mode of transport. The expats and number of employees also show a significant positive influence in user characteristics. Public transport stations appear to have no significant influence.

Table 2 shows the result of the multiple regression analysis with an adj. R^2 of 48%. Positive correlations are shown for number of employees, number of people between 15-24 and 25-44 as well as number of vehicles per household and percentage of expats.

Gegevens voor de regressie								
Meervoudige correlatiecoëfficiënt R	72%							
R-kwadraat	52%							
Aangepaste kleinste kwadraat	48%							
Standaardfout	68,55050991							
Waarnemingen	157							
Variantie-analyse								
	Vrijheidsgraden	*Kwadratensom*	*Gemiddelde kwadraten*	*F*	*Significantie F*			
Regressie	11	727304,8033	66118,61848	14,07026871	3,89247E-18			
Storing	145	681379,9992	4699,172409					
Totaal	156	1408684,803						
	Coëfficiënten	*Standaardfout*	*T- statistische gegevens*	*P-waarde*	*Laagste 95%*	*Hoogste 95%*	*Laagste 95,0%*	*Hoogste 95,0%*
Snijpunt	-94,23816856	42,5969131	-2,212323891	0,028508299	-178,4292448	-10,04709231	-178,4292448	-10,04709231
Trein	0,850597883	18,27966518	0,046532465	0,962949885	-35,27842116	36,97961692	-35,27842116	36,97961692
Bus/tram	1,279640363	1,569600565	0,815264973	0,416257758	-1,822611684	4,381892409	-1,822611684	4,381892409
Metro	-4,526184655	4,12917628	-1,096147112	0,274831616	-12,6873346	3,634965289	-12,6873346	3,634965289
werkzame personen	0,009451645	0,005092988	1,855815547	0,06550978	-0,000614438	0,019517729	-0,000614438	0,019517729
15-24 jaar	0,174129966	0,054261741	3,209074424	0,001639502	0,066883829	0,281376104	0,066883829	0,281376104
25-44 jaar	0,071143749	0,018216321	3,905494892	0,000143678	0,035139927	0,107147571	0,035139927	0,107147571
gemiddelde WOZ-waarde	-5,79226E-05	4,59434E-05	-1,260740333	0,209427296	-0,000148728	3,28825E-05	-0,000148728	3,28825E-05
auto_hh	190,4968565	43,19100838	4,410567469	1,99703E-05	105,131575	275,862138	105,131575	275,862138
bev_dichth	-0,000757367	0,001019594	-0,742812347	0,458797029	-0,002772554	0,00125782	-0,002772554	0,00125782
p_west_al	2,129600548	1,157758728	1,839416534	0,067899166	-0,158662762	4,417863858	-0,158662762	4,417863858
m2_winkel	0,000323619	0,000467661	0,691995147	0,490046984	-0,000600694	0,001247933	-0,000600694	0,001247933

Table 2: Multiple regression analysis of usage

The final analysis shows the time that vehicles are parked somewhere before they are picked up. We notice that areas in the city centre are often parked shortly before being picked up again. The first circle around the city centre is a bit longer where areas around that circle are longer. The waiting time might be correlated with the number of different functions in a city or the population density. If a neighbourhood has solely residential areas it is likely that vehicles all arrive in the evening and do not leave until the next morning, where areas with many different functions have different movement demands on different times of the day and therefore stay mobile. Simultaneously, the more people live or work in close proximity to one of the FFECS vehicles the larger the number of people is that is likely to use one of them.

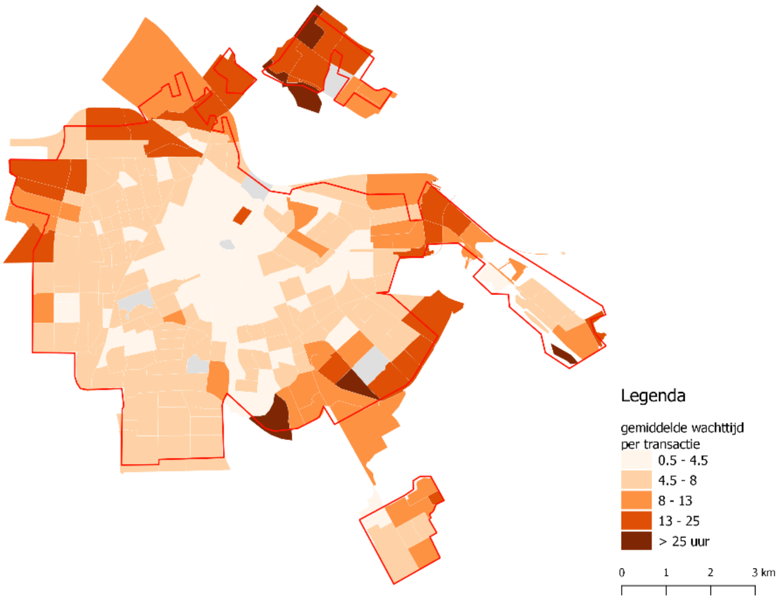

Figure 2 Average idle time for a FFECS vehicle. Darker colours mean longer waiting time.

4.2 Charging station location

The location study focuses on the charging station requirements regarding location. We see that availability of free charging stations is a key factor (fig. **3**). Figure **3** shows how capacity utilization of charging stations differ considerably between neighbo**u**rhoods, dark blue being highly used (and limitedly available) and in light blue relatively well available. Note that availability may differ between neighbo**u**rhoods in terms of time of day, depending whether it is an office neighbourhood (availability high at night) or a residential area (availability higher during the day). In areas where charging stations are often available but parking pressure is high, people tend to park (and therefore charge) their FFECS vehicles as it is simply the first available parking spot.

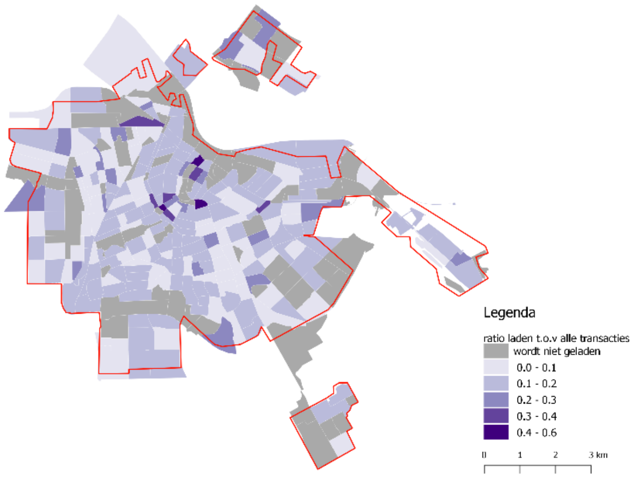

Figure 3 shows the ration between transactions left at charging stations and those that are not. The darker blue to area the higher the ratio.

Availability therefore appears to play an important part in the decision of someone to leave their vehicle at a charging station. Using a multiple regression we focused on findability and expected availability. Findable charging stations are defined as charging stations located next to a major road. If people see a charging station on their route it's easier to find than the charging stations that are in smaller streets in the neighbourhood. We measure expected availability as charging plazas. Charging plazas are locations where multiple charging stations are located next to each other and therefore it might be more convenient to drive to one plaza with two or more charging stations instead of driving through neighbourhoods and checking 'solo station' availability.

The hypothesis of higher availability as an important factor seems to be in line with the results of the multiple regression analysis (see table 3). If vehicles are clustered on a so-called charging plaza they are 2,93 times more likely to be used than if they are on standalone basis. If charging stations are next to a major road they are 18% more likely to be used and if they are in close proximity to a train station (<500m) they are 30% more likely to be used. This means that findability (major roads) and availability (plazas) both play an important role where the latter appears to be the most important one.

Gegevens voor de regressie	
Meervoudige correlatiecoëfficiënt R	46%
R-kwadraat	21%
Aangepaste kleinste kwadraat	20%
Standaardfout	3,375096957
Waarnemingen	697

Variantie-analyse

	Vrijheidsgraden	Kwadratensom	Gemiddelde kwadraten	F	Significantie F
Regressie	12	2061,113134	171,7594279	15,07815064	2,38397E-28
Storing	684	7791,635158	11,39127947		
Totaal	696	9852,748293			

	Coëfficiënten	Standaardfout	T- statistische gegevens	P-waarde	Laagste 95%	Hoogste 95%	Laagste 95,0%	Hoogste 95,0%
Snijpunt	2,624385148	1,516551766	1,730494934	0,083992905	-0,353270609	5,602040905	-0,353270609	5,602040905
laadplein	5,052769236	0,472555631	10,6924326	8,82467E-25	4,12493543	5,980603042	4,12493543	5,980603042
hoofdweg	0,459319269	0,266046801	1,726460411	0,084716147	-0,063047198	0,981685736	-0,063047198	0,981685736
p_15_24_jr	-0,013731983	0,030694014	-0,447383108	0,65474011	-0,073997785	0,046533818	-0,073997785	0,046533818
p_25_44_jr	0,076355841	0,021284189	3,587444179	0,00035775	0,034565649	0,118146032	0,034565649	0,118146032
Bev_dichtheid	-8,21723E-05	2,34888E-05	-3,498359795	0,000498446	-0,000128291	-3,60535E-05	-0,000128291	-3,60535E-05
p_wes_al	0,016359557	0,013670735	1,19668452	0,231844153	-0,010482087	0,0432012	-0,010482087	0,0432012
auto_hh	-1,211852077	1,683734184	-0,719740734	0,47193049	-4,517760189	2,094056036	-4,517760189	2,094056036
gem_WOZ	0,011330215	0,00554874	2,0419438	0,04154018	0,000435607	0,022224824	0,000435607	0,022224824
ink_ontv	-0,132567596	0,074089434	-1,789291535	0,074010213	-0,278037625	0,012902432	-0,278037625	0,012902432
treinstations_500m	0,769945477	0,396537152	1,94167299	0,052586979	-0,008630738	1,548521692	-0,008630738	1,548521692
bus_tram_haltes_500m	0,008126959	0,019126109	0,424914382	0,671032723	-0,029425975	0,045679893	-0,029425975	0,045679893
metro_haltes_500m	0,083921573	0,090601118	0,926275242	0,354629657	-0,093968129	0,261811275	-0,093968129	0,261811275

Table 3 the effect that location seems to have on the number of expected transactions of FFECS vehicles.

5 Modelling The Hague

We investigated and implemented the model for the city of The Hague to understand the preparation required and impact that such a system could make for the city. We modelled the results acquired from the multiple regression analyses for the city. The results are shown below.

5.1 Predicted business area

Analysing the city of The Hague shows that the city centre and more importantly the areas around the city centre are likely to be interesting neighbourhoods for a FFECS system – given their demographic characteristics. We used the variables retrieved from the multiple regression analysis to predict which neighbourhoods would be most attractive and susceptible for car sharing systems (see fig. 4). It shows that especially the centre and south west of the centre (green areas) are likely to be interesting neighbourhoods for an FFECS system. Less interesting are the areas more in the outskirts of the city.

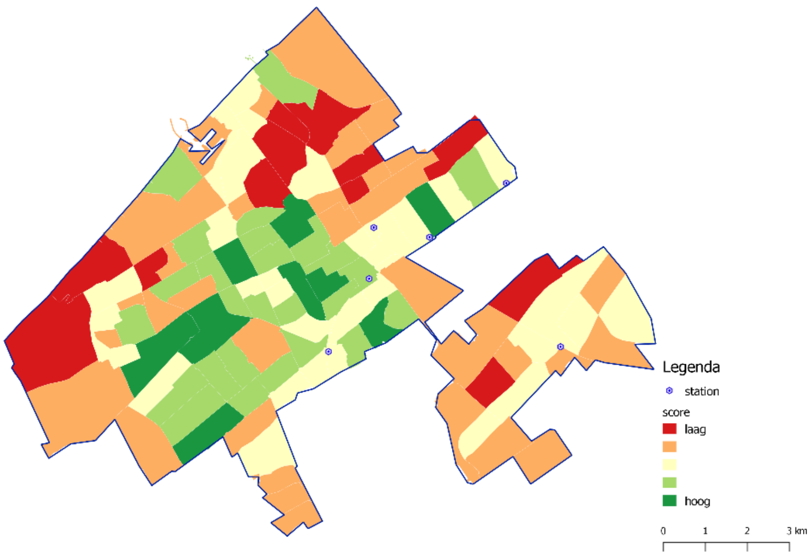

Fig. 4 Map of predicted interesting demography of The Hague, where green is high and red is low

5.2 Rides and charging in The Hague

The result shows a more detailed number of expected charging sessions per neighbourhood using the multiple regression analysis of Amsterdam. Using the results of the demographic analysis we estimated an expected number of transactions per neighbourhood in The Hague. As an average 11.2% of all rides end at a charging station and availability appears to be a key aspect in the decision to end the ride at a charging station, we estimated that 11.2% of all rides would end at a charging station. This results in an expected charging demand. On the supply side we estimated the expected usage of all charging stations based on their location (plaza, big road, train station) and combined the information to see if supply and demand match (see fig. 5). We see that many neighbourhoods (dark green) have plenty of charging stations and the light green ones are the ones where supply and demand are closely linked. The yellow and orange ones need some attention as charging stations might not be able to supply the vehicles with an optimal charging infrastructure. The red and dark blue neighbourhoods are the ones where there is a significant shortage (red) or even absence (dark blue) of charging stations even though there is a demand that requires more charging stations. We recommend the municipality to extend their network to these areas so that FFECS vehicles become easier and more interesting to park and charge.

The number of charging sessions is mapped in fig. 5. The impact of a new FFECS system on the charging network as a whole is expected to be limited as the network is extensive and therefore the extra number of charging sessions will not dent the network in general. However, in some neighbourhoods where charging infrastructure is limited or even fully absent the implementation might cause some distress to the current electric drivers .

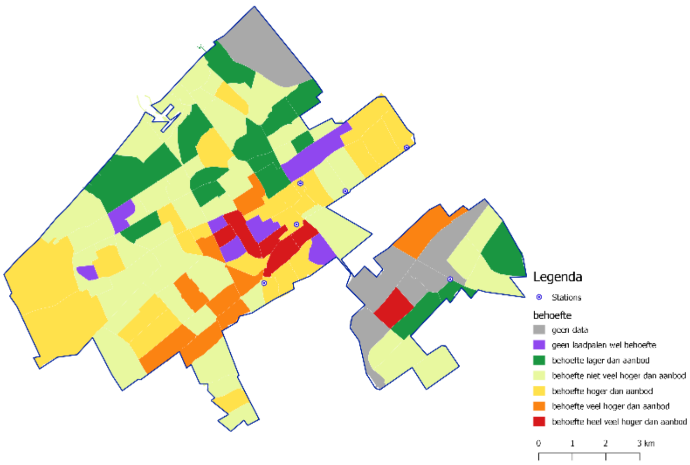

Fig. 5: Number of expected transactions per neighbourhood versus the current number of charging stations

6 Conclusion and Discussion

The research provides some first applicable and exploratory insights for cities regarding FFECS systems. Implementing such a system can reduce car ownership, promotes electric driving, reduces air and noise pollution and might even reduce the total amount of kilometres driven. This research provides some guidance regarding the charging infrastructure required to facilitate FFECS systems. This paper describes a three-step approach that may support municipalities in preparing and optimizing the rollout of charging infrastructure in view of likely charging locations of e-car sharing vehicles. The approach entails (i) analysing likely neighbourhoods for car sharing demand, (ii) more detailed analysis of possible charging demand as a result, (iii) analysis of current charging infrastructure capacity in view of increased demand (in turn leading to possible roll out recommendations).

The business area of FFECS systems is largely impacted by the number of people under the age of 45 that reside there and the low number of vehicles per household. The number of rides is also higher in neighbourhoods with the same age group, but here the number of vehicles per household appears to have a positive impact as well as the number of employees and percentage of expats. This implies that areas that are more built towards car ownership and usage see a higher FFECS usage than those that are not. The hypothesis that FFECS vehicles are a back-up for other modes of transport was not confirmed nor denied. The correlation between public transport stations and FFECS usage was mostly non-significant and this might be due to the large number of rides on bicycles.

Charging has a key role in an electric FFECS system even though only a fraction of the rides end at a charging station. The availability appears to play an essential role. Areas where people often charge appear to have a higher parking pressure than the charging stations. Simultaneously, charging stations that are located in close proximity to each other are more popular than those that are by themselves. Making charging visible (along major roads) with a high expected availability (multiple chargers in close proximity) make it easy for people to leave their vehicle at a charging station, which appears to be necessary. Regarding the current number of charging stations, the city of The Hague should be able to host a FFECS system. The neighbourhoods have the desired demographic characteristics and the charging network is extensive enough to facilitate the system. However, a few neighbourhoods show a significant shortage of charging stations that should be included to increase usage in these neighbourhoods as well. When expanding the network to facilitate FFECS vehicles the focus should be on charging plazas and if possible proximity to highly visible roads and/or train stations.

Further research might expand the number of cities analysed, the number of days analysed, different levels of scale and might include time frames, a further focus on seemingly contradicting correlations and a more explanatory methodology.

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