Project: Electric vehicle charging stations

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1 Executive Summary

In our report we focus on finding how many charging points are expected to need to exist in each grid by analysing some information relating to the estimated total energy demand for EV charging, the potential number of charging stations, the number of points of interest in each grid and the distance from each grid to the city centre over the next four years. For the charging stations that already exist in Dundee, we set the presence of 2 charging points per charging station. Next, we will disregard the number of charging stations and only consider how many charging points exist in the grids where they are likely to exist.

In the modelling part, with established constraints in order to satisfy suitable percentage of expected demand, avoid too much chargers and traffic in one single grid square, especially in the city center, and have a variety of different types of new chargers. We also established the objective function trying to have new chargers built in grids that already have charging stations, reducing extra establishing cost. The model gives us 253 new chargers to be built in the first year, which will increase as time goes by.

After the results we obtained, we think that the model can be further investigated to obtain more and more useful results. For example, each charging point could be pinpointed to a more precise coordinate location so that people could immediately find the charging point when they need to charge their electric vehicle. The location of charging points could also be modelled so that they are close to restaurants, schools and shopping centres, as these areas have a high traffic flow and most people spend time in these areas, which would not only provide convenience but also increase the profitability of charging points near these areas.

2 Introduction

With the push for a sustainable transport sector, there are challenges in re-designing these transport networks. In the field of personal transport, the use of battery electric vehicles has become a popular and sustainable alternative because of the advantages of using electricity, no exhaust emissions while driving and no environmental pollution. However, electric vehicles require regular charging and have a short range. So our goal is to plan how to set up their charging infrastructure in the Dundee and to make some proposals.

To get a better visualisation of where we will build charging stations, we have divided the map of Dundee into 434 grids of equal size.

In our report we focus on finding how many charging points are expected to need to exist in each grid by analysing some information related to the estimated total energy demand for EV charging, the potential number of charging stations, the number of points of interest in each grid and the distance from each grid to the city centre for each of the next four years.

For the charging stations already present in Dundee, we set the presence of 2 charging points per charging station. Next we will disregard the number of charging stations and only consider how many charging points are present in the grids where charging stations are potentially present.

There are three types of charging points, namely rapid charging points, fast charging points and slow charging points. As the council is not sure exactly how much demand can be met by a single charging station, after analysing data from previous years, the council has estimated the annual demand that can be met by a single connector for each charging type, as follows,

- Slow chargers can satisfy between 2000 kWh/year and 3500 kWh/year
- Fast chargers can satisfy between 4000 kWh/year and 5200 kWh/year
- Rapid chargers can satisfy between 30000 kWh/year and 50500 kWh/year

We have made Figure 1 based on the given data. Red indicates cells where charging stations are currently present, blue indicates cells where there are no charging stations. Figures 2 and Figure 3 are also similar to Figure 1, indicating the grids we are interested in and the grids where charging stations potentially exist, respectively.

We can see that in the above diagram, any red grid (i.e. where a charging station exists) will be surrounded by 8 grids, meaning that if an electric vehicle needs to be charged when it is in an area with 8 grids, it can be charged at the designated red grid, thus avoiding the greatest waste of resources. Most grids are

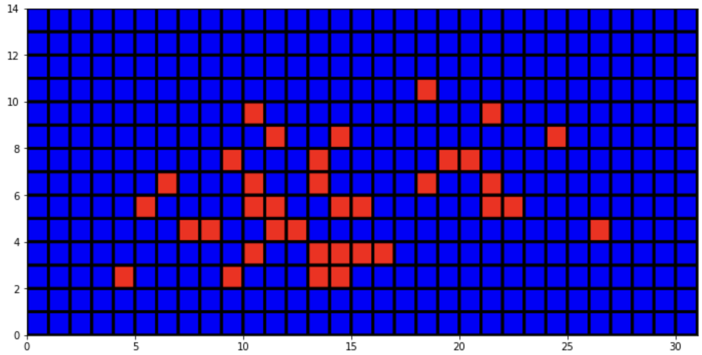

Figure 1: Grids where charging stations are currently present and those where they are not.

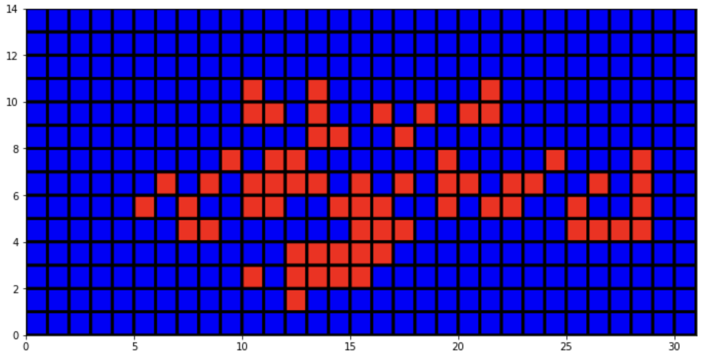

Figure 2: The grids that we are interested in can have charging stations in the red grids.

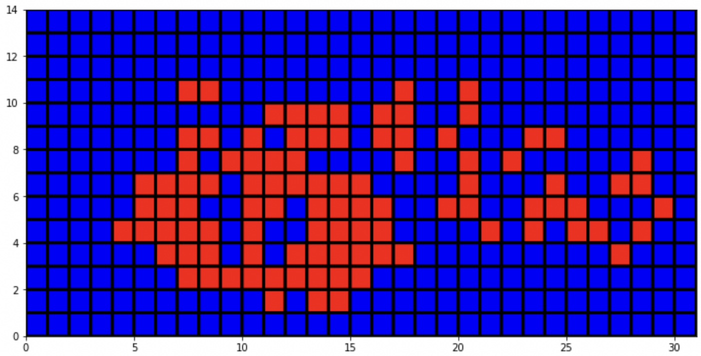

Figure 3: Grids in red are grids where a charging station could potentially be established.

surrounded by 8 neighbours, but if a given grid is on the edge or in a corner, then only 3 or 5 neighbours exist.

3 Variable Definition

We establish some notations and define some decision variables.

3.1 Notations

Let the three charger types “slow”, “fast”, and “rapid” be type $k = 1, 2, 3$, respectively and let K be the charger type index set.

Let the next four years be year $t = 0, 1, 2, 3$, respectively and let T be the year index set.

Let the indices the demand grids for electric charging stations be grid $i = 1, \ldots, 434$, respectively and let I be the grid index set.

Let the indices set of grids of city center, which is the 25 grids including and around grid 214, be grid $i = 184, 185, 186, 187, 188, 198, 199, 200, 201, 202, 212, 213, 214, 215, 216, 226, 227, 228, 229, 230, 240, 241, 242, 243, 244$, respectively and let $citycenter$ be the city center grid index set.

Let the indices of lower bound of energy a singer connector can satisfy per year and the upper bound be energy index $e = 0, 1$, respectively and the E be the energy index set.

$satdemand_i$: The amount of energy that can be provided by the current charging points in grid i. And it needs to multiple two, since each charging point consists of two connectors.

$chargerpower_{k,e}$: Let $chargerpower_{k,e}$ be the amount of energy a single connector of type $k \in K$ can provide per year, with $chargerpower_{k,0}$ denoting the lower bound and $chargerpower_{k,1}$ denoting the upper bound.

$chargepoint_{k,i}$: Let $chargepoint_{k,i}$ be the number of current charging points with charger type $k \in K$ in grid $i \in I$.

$neighcount_i$: Let $neighcount_i$ be the number of neighbour grids of grid $i \in I$.

Let the neighbour index of each grid be $n = 1, \ldots, neighcount_i$ (which varies depending on the each grid), respectively and the N_i be the neighbour index set of grid i.

$neighbour_{i,n}$: Let $neighbour_{i,n}$ be grid index of the nth neighbour of grid $i \in I$. For each $i \in I$, $n \in N_i$.

nopotential: Let *nopotential* be grid index set of the grids with no potential charging points in the next four years. For one such grid i, $i \in nopotential$.

$currentpoint_i$: Let $currentpoint_i$ be 1 if there is any current charging point in grid i, and let $currentpoint_i$ be 0 if otherwise. For each $i \in I$.

$demand_{t,i}$: Let $demand_{t,i}$ be the expected demand in grid $i \in I$ for year $t \in T$.

For any grid $i \in I$, $satdemand_i$ can be calculated by $chargepoint_{k,i}$ and $chargerpower_{k,e}$, with one charging point having two connectors, and each connector satisfying certain amount of demand:

$$satdemand_i = 2 \times \sum_{k=1}^{3} chargerpower_{k,1} \times chargepoint_{k,i} \tag{1}$$

3.2 Decision variables

$x_{k,t,i} \in Z$: The number of chargers of type k will be built in grid i in year t (in this report, we use one single charger to denote a single charging connector). $k =$ 1,2,3, $t =$ 0,1,2,3, and $i =$ 1, ..., 434.

$y_{t,i}$: In year t, for grid i, the amount of demand that can be satisfied by grid i and its neighbour grids. $t =$ 0, 1, 2, 3, and $i =$ 1, ..., 434.

4 Constraints

1. The amount of energy supplied by the three types of chargers needs to meet the expected demand for each year. But not every grid is equipped with sufficient electric vehicle charging stations. We assume if one grid has chargers then it can also supply the energy to its neighbour grids. And the energy supplied to every grid each year is provided by both the current charging points and the new chargers built before and in this year, by the grid itself and its neighbour grids. This constraint is for all $k \in K$, $t \in T$, $i \in I$, and $n \in N_i$. Therefore, the first constraint can be written as follows:

$$\begin{aligned} y_{t,i} = \sum_{t1=0}^{t} \sum_{k=1}^{3} chargerpower_{k,1} \times x_{k,t1,i} + satdemand_i + \\ \sum_{n=1}^{neighcount_i} (\sum_{t1=0}^{t} \sum_{k=1}^{3} chargerpower_{k,1} \times x_{k,t1,neighbour_{i,n}} + satdemand_{neighbour_{i,n}}) \end{aligned} \tag{2}$$

$$y_{t,i} \geq 80\% \times demand_{t,i} \tag{3}$$

2. There can not be too many charging points in a grid. This is because if

the charging points all concentrates in one grid, it is not convenient for customers in other grids to charge their vehicles. And too many charging points will cause the traffic jams. The maximum number of charging points in each grid can be calculated through dividing the expected demand for each year of the grid itself and its neighbour grids by the minimum of the demand of a single connector can satisfy, substracting the number of current chargers. For this question, we can find the minimum demand a single charger can satisfy is that of slow chargers with 2000KWh/year. We choose to calculate the maximum number of chargers by 80% of expected demand for the grid and neighbour grids. The constraint is for all $k \in K$, $t \in T$, $i \in I$, and $n \in N_i$:

$$\sum_{k=1}^{3} x_{k,t,i} \leq 80\% \times \frac{demand_{t,i} + \sum_{n=1}^{neighcount_i} demand_{t,neighbour_{i,n}}}{chargerpower_{1,0}} - \sum_{k=1}^{3} chargepoint_{k,i} \tag{4}$$

3. The council also intends to limit the number of charging stations in the city centre, avoiding increasing traffic in the city center. We assume the city centre is the 214th grid, and define the 25 grids including and around the 214th as the city centre. In these grids, we calculate by only 60% of the expected demand for each year. The constraints is for all $k \in K$, $t \in T$, $i \in citycenter$, and $n \in N_i$:

$$\sum_{k=1}^{3} x_{k,t,i} \leq 60\% \times \frac{demand_{t,i} + \sum_{n=1}^{neighcount_i} demand_{t,neighbour_{i,n}}}{chargerpower_{1,0}} - \sum_{k=1}^{3} chargepoint_{k,i} \tag{5}$$

4. Across the UK, rapid and ultra-rapid chargers make up for approximately 20% of total electric vehicles charging devices[1]. Using rapid chargers is efficient and time saving, however not all electric vehicles can be charged with rapid charging devices, especially plug-in hybrid vehicles. Therefore, the council would like to see a variety of charger types. In order to avoiding making customers having no suitable type of chargers for their vehicles, we limit upper bound of the sum of rapid chargers built in the next four year to be 40% of the sum of all three types. And to have a variety of different types of chargers, we limit the lower bound of the sum of each type of chargers to be built in the next four years to be 20% of the sum of all three types. The constraints are for all $t \in T$ and $i \in I$:

$$20\% \sum_{t=0}^{3} \sum_{k=1}^{3} x_{k,t,i} \leq \sum_{t=0}^{3} x_{3,t,i} \leq 40\% \sum_{t=0}^{3} \sum_{k=1}^{3} x_{k,t,i} \tag{6}$$

$$\sum_{t=0}^{3} x_{1,t,i} \geq 20\% \sum_{t=0}^{3} \sum_{k=1}^{3} x_{k,t,i} \tag{7}$$

$$\sum_{t=0}^{3} x_{2,t,i} \geq 20\% \sum_{t=0}^{3} \sum_{k=1}^{3} x_{k,t,i} \tag{8}$$

5. If one grid does not have potential charging points, then we can not build chargers in the next four years in this grid. For such grids, we set the sum of all three types of chargers to be built in the next four years equal to zero. The constraint is for all $t \in T$ and $i \in nopotential$:

$$\sum_{k=1}^{3} x_{k,t,i} = 0 \tag{9}$$

6. We assume all the decision variables are non-negative. The constraint is for all $k \in K$, $t \in T$ and $i \in I$:

$$x_{k,t,i} \geq 0 \tag{10}$$

$$y_{t,i} \geq 0 \tag{11}$$

5 Objective Function

The council expects that if an electric charging point has been established at a potential charging location, then to place another charging point at the same location would come at a reduced cost. In our model, it is hard to come out with a specific charging location. Instead, we will try to build new chargers in grids with current charging points, in order to reduce establishing costs. Therefore, we use the $currentpoint_i$ for each grid $i \in I$ to establish the objective function, maximizing the number of all three types of chargers to be built in grids already having "current charging points" in the next four years. The objective function is as follow:

$$\max_{x} \sum_{i=1}^{434} (currentpoint_i \times \sum_{t=0}^{3} \sum_{k=1}^{3} x_{k,t,i}) \tag{12}$$

6 Results

In conclusion, we can obtain the number of slow chargers, fast chargers and rapid chargers to be established needed for each year. The results are shown as follows:

new chargers	first year	second year	third year	fourth year	total
slow	33	10	301	159	503
fast	193	132	0	304	629
rapid	27	159	143	210	539
total	253	301	444	673	1671

Also, the growth rate of the number of new chargers of the second year, the third year and the fourth year are 19.0%, 47.5% and 51.6%, respectively. We also calculated the percentage of the total number of charging points built in the city centre (the 214th grid and its around 24 grids). In year 1, the percentage of new chargers built in city center is nearly 34.4%. In year 2, the percentage is approximately 50.8%. In year 3, the percentage is around 55.9%. In year 4, the percentage is nearly 58.6%. And the grids with new chargers to be established in the next four years are shown as red grids in the figure below.

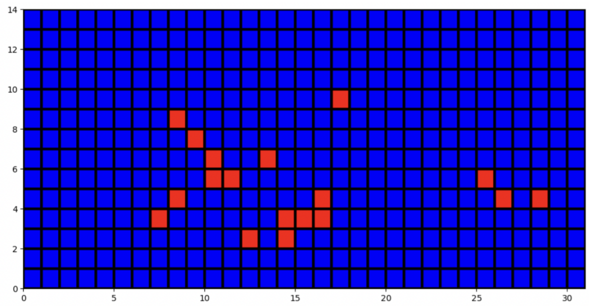

Figure 4: Grids where new chargers are established and those where are not.

7 Conclusions

After the results we got, we think that further research can be done for this model to get more and more useful results. For example, each charging point could be pinpointed to a more precise coordinate location so that people can find the charging point immediately when they need to charge their electric vehicle. It is also possible to model the location of charging points closer to restaurants, schools and shopping malls, as these areas have a higher traffic flow and most people stay in these areas for a period of time, which will not only provide convenience but also increase the profitability of charging points near these areas.

References

[1] Admin (Zap-Map). How many electric charging points in the uk 2022 - zap-map, Nov 2022. URL: `https://www.zap-map.com/statistics/`.