Flinders University
College of Science & Engineering

USING ORIGIN DESTINATION DATA TO DETERMINE THE POTENTIAL FOR ELECTRIC VEHICLES TO BECOME VIRTUAL POWER PLANTS

THESIS

ENGR9700 – Master Thesis

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I have provided feedback on this document and the student has implemented it minimally/partially/fully.

Declaration

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Signed by the Declarant – Rider Hugo Reategui Gomez

In Adelaide on the 8th of November 2021

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Executive Summary

The purpose of this project is to use data MASTEM (data traditionally used by the DPTI) to estimate how much charge is remaining when the Electric Vehicle (EV) arrives at its final destination/home in Metropolitan Adelaide. The research question is that these vehicles could become part of a Virtual Power Plant (VPP). EV batteries can provide energy to the home during peak energy demand, thereby reducing peak demand.

Regarding the methodology used in this research, it has been analysed: Number of trips in 24 hours, Distance between each zone, Estimation of vehicle kilometres of travel (VKT), Estimation of EVs sales in South Australia, Estimation of average EV Energy Consumption (Wh/km), Estimation of average Battery Capacity (kWh), Confidence interval: Lower & Upper boundary, Registered vehicles by postcode, Vehicles by MASTEM Zones, Energy Remaining in EVs, Number of vehicles in each scenario, Estimation of Electricity Consumption in South Australia, and Distribution of driving distances. Likewise, for the purposes of calculating and estimating, some assumptions have been made, such as i) it has been considered that all vehicles in SA are EVs and ii) Vehicle kilometres travelled (VKT) from one travel analysed zone to all other zones are round trips in each zone.

The results were analysed for three scenarios: the lower boundary, the mean, and the upper boundary (95% confidence intervals). Total energy storage for the lower boundary was 26,560,050 kWh, the mean was 35,496,603 kWh and for the upper boundary was 44,437,236 kWh. It was also estimated that the electricity consumption per day in South Australia is 10,270,582 kWh. This shows that in the less favourable scenario, the batteries of the EVs could cover the energy demand of the SA population, assuming that the entire fleet of vehicles is electric.

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1 Introduction

The South Australian government is committed to taking action against climate change by offering a cleaner environment and a more productive electricity grid by including Electric Vehicles (EVs) in them. South Australia is estimated to be a leader in the adoption of EVs and smart charging by 2025, leveraging renewable energy to reduce automotive costs, air pollution, noise and carbon, and lower electricity costs for all Australians (Department for Energy and Mining, 2020). Although there has been an increase in EVs sales in recent years, the number of EVs in Australia is much lower compared to other developed countries. However, there is a survey that gives reason to be optimistic that this gap will narrow in the coming years (Electric Vehicle Council, 2020). EVs through their batteries can provide energy to the grid and help manage energy demand, through Virtual Power Plants (VPPs) (Australian Energy Regulator, 2021). It is estimated that the battery of 19 million EVs would probably exceed 1,800 gigawatt hours which is equivalent to more than 10,000 "Tesla big batteries" (Sturmberg, 2020).

The traditional transport and energy sectors must work together in electric vehicles. (Electric Vehicle Council, 2020) and through this report we attempt to use traditional transport data modelling (Origin-Destination data) to estimate the potential of passenger EVs to feed energy into the household and the power grid.

1.1 Aim

“This project aims to use OD data to attempt to approximate how much charge would be left in an electric vehicle when it arrives at its final destination/home in Metropolitan Adelaide”.

1.2 Objectives

- Analyse the origin and destination of passenger vehicles (vehicles) across the metropolitan area.
- Use transport Origin-Destination (OD) data by time of day (24-hour Origin-Destination Matrix) to obtain the estimation of Vehicle Kilometres of Travel (VKT).
- Investigate Australian EVs sales to obtain the proportion of EVs sold in South Australia and estimate the average of EVs consumption and EVs storage capacity to use in our calculations.
- Estimate EVs battery consumption over the metropolitan area to calculate the energy remaining in EVs.

2 Literature Review

South Australia Government´s target is to achieve a net-zero emission by 2050 reducing its greenhouse gas emission. South Australia has been able to reduce greenhouse gas emissions by 33% from 2005 to 2019. As it is possible to see in Figure 2.1, Transport was the major emission source with 28% of total net greenhouse gas emissions in the 2019 financial year (Department for Environment and Water, 2019). This trend can also be appreciated in the summary on annual greenhouse gas emissions where for the year to March 2020 and 2021 the transport sector reduced its values by 13.22% (Australian Government Department of Industry, Science, Energy and Resources, 2021). The South Australian Government plans to shift from fossil fuel combustion engines to electric transport, which includes private and public transport through the adoption of Electric Vehicles (EVs) hence delivering clean energy and boosting the electric grid. In the coming years, a transition is being sought to have all government fleets and public taxis, and shared rides are completely electric, the expectation by 2035 is that every new passenger vehicle sold to be fully electric to have electrification of transport net zero-emission fleet by 2050. Having this South Australia wants to become a global leader in distributed energy sources such as solar and batteries, and incorporate EVs into Virtual Power

Plants (VPPs) that will help to power and balance their grids, while also rewarding consumers (Department for Energy and Mining, 2020).

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Figure 2.1: South Australia's greenhouse gas emissions in the 2019 financial year. Source: Australian Greenhouse Emissions Information System, Department of Industry, Science, Energy and Resources (2021).

The shift to EVs supports climate change and South Australia´s economic development. Unlike conventional fossil fuel-powered vehicles, which are parked without providing extra value for about 90% of the day, EVs can generate new sources of income while they are parked and plugged into a VPP. The goal of South Australia is faster adoption of sustainable technologies and practices required to be prepared for this transition to EVs (Department for Energy and Mining, 2020). The contribution of EVs charging could make to increase electricity consumption and use efficiently during off-peak periods and high production of renewable energy in order to reduce the price of electricity (AEMC, 2020). A Virtual Power Plant (VPP) is a way to generate and manage energy, it can store energy and supply it to the grid. It is a network basically controlled by Rooftop PV and battery systems working together. A VPP uses the energy to meet household needs and the additional storage energy can be shared with the community when they need it (Department for Energy and Mining, 2020).

For the development of this report, information on two types of light passenger EVs will be used, Battery Electric Vehicles (BEVs) and Plug-in Hybrid Vehicles (PHEVs). According to the Electric Vehicle Council (2020), Australia has 28 EV models available from 11 different carmakers, 12 are BEVs and 16 PHEVs. Global EVs sales in 2019 continued to grow to 2.26 million vehicles, an increase of 9% over the previous year. Australia’s market sales still lag behind other developed countries where EVs sales represent between 2.5% and 5% of the overall sales. EVs sold represent 0.6% of Australia’s vehicle sales in 2019; however, the continued introduction of new models provides opportunities for growth. In the first half of 2020, 3,226 EVs were sold despite a decline in overall vehicle sales (Electric Vehicle Council, 2020). In Figure 2.2 is possible to appreciate that Victoria, NSW and Queensland have the highest total number of EVs followed by SA with 412 sales. However, South Australia sold 61 EVs for every 10,000 vehicle, a much higher value compared to the aforementioned, only falling below ACT which has 83 EVs for every 10,000 sales.

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Figure 2.2: Electric vehicle market penetration across Australian states and territories. Source: Electric Vehicle Council (2020)

Having analysed the literature on EVs and their sale in Australia, let us now review the distribution and consumption of the energy generated in SA. In relation to this, we can start with Figure 2.3 that shows the average daily supply profile for South Australia for the 2019-20 financial year. It can be seen coloured in light yellow the energy produced by Rooftop PV (photovoltaic) and the daily energy usage (Operational Demand) represented by a purple line which is similar to daily traffic volume profiles showing AM and PM peak periods. The interesting thing about this figure above is that it shows that the greatest amount of energy obtained by Rooftop PV occurs in hours when the energy demand is lower, which indicates that the solar energy is not being adequately used.

Additionally, the production of the energy obtained by the Rooftop PV in the most favourable conditions has been analysed as shown in Figure 2.4, as it can be seen the energy production can vary every day and will naturally increase when more Rooftop PVs are installed. The Australian Energy Regulator (2021) generated a specific analysis for March 14, 2020 (Figure 2.4), a record day for low energy use and high solar energy production. That day the temperature was 21°C and the skies were clear in Adelaide, ideal conditions for Rooftop PV energy generation and the mild climate reduced the need to use heating or air conditioning, it was a Sunday. Solar and wind generation depends on meteorological variables, which may not match the energy needs of the population. However, despite having obtained a higher energy production given the excellent climatic conditions, note also that, like the profile shown in Figure 2.3, it is confirmed that the energy obtained by Rooftop PV cannot be used in the peaks of higher energy demand. Therefore, it is required to store this energy to create a balance that matches the supply and demand of energy (Timoth, et al., 2020) and the contribution of EVs batteries could store energy during high production of renewable energy and make efficient use during off-peak periods (AEMC, 2020).

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Figure 2.3: Daily supply profile for South Australia averaged for the 2019-20 financial year. Source: AEMO (2020)

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Figure 2.4: South Australia local generation mix and grid demand 14 March 2020. Source: AER analysis of AEMO data (2021)

In fact, EVs batteries have a large storage capacity to contribute to our electricity grid. For instance, 3,500 EVs, which is 5% of light passenger vehicle sales, would add 175 MWh of energy storage to the electricity grid each year. Under the VPPs, this storage capacity will support the grid and further reduce energy costs for all South Australians, such as Hornsdale Power Reserve (193.5 MWh) near Jamestown, also known as the Tesla Big Battery (Department for Energy and Mining, 2020). The Motor Vehicle Census from 2021 revealed that South Australia has 1,477,899 vehicles registered (Australian Bureau of Statistics, 2020) and according to the Global EV Outlook (2020) the estimated average battery size range between 48 kWh and 67 kWh. However, it is not known what the battery range is in the South Australian vehicle fleet and this study will research it and calculate the number of vehicles for Metropolitan Adelaide.

Energy storage is advancing, through grid-scale and household batteries, and pumped hydro-generation plants. Although they are still in their early stages, technologies that include hydrogen and EVs will have an impact on both electricity supply and demand. In the near future, VPPs users will increasingly store surplus energy from Rooftop PV systems in EVs' batteries and use them as needed. They will control their own energy use, power bill and they will also be able to feed the electric grid and receive an economic benefit (Australian Energy Regulator, 2021). This interesting finding demonstrates the important use of EV batteries as a storage source, but this study has not analysed what the behaviour would be in SA, so that gap will be evaluated in the present investigation.

This report targets to estimate how much energy will be left on EV batteries using transport Origin-Destination (OD) data in Metropolitan Adelaide. OD data was sourced from the Metropolitan Adelaide Strategic Transport Evaluation Model (MASTEM), it is the Department of Planning, Transport, and Infrastructure's (DIT) preferred strategic travel demand model and was built within the Cube software package by Citilabs. By knowing consumption, we can know an indicator of how much energy is left in batteries to be used in VPPs.

Origin-destination surveys are traffic studies used in transport planning and traffic engineering which provide valuable information on where motorists desire to travel, their origin, destination and travel times and the volume of trips. With this information, essential travel patterns (trip distribution) can be obtained from traffic studies, whether at the local, regional, or metropolitan level. These can range from simple studies to comprehensive transportation studies that are used in the planning and design of transportation systems in large metropolitan areas (Austroads, 2013).

EVs require the transport and energy sectors to work together (Electric Vehicle Council, 2020). Using transport data modelling like OD transport data set to determine the potential for EV becoming a VPP we expect to contribute to reducing the gap between the two sectors.

In the final stage of this investigation, it has been identified that the Aimsun company has recently updated its software. Aimsun Next is a mobility modelling software designed to carry out traffic operations assessments of any scale and complexity. The software provides us with transportation analysis and optimization, its latest version includes EVs analysis. As it is possible to appreciate in Figure 2.5, the software offers a Battery Consumption Model for EVs in microscopic simulations. The model estimates the energy consumption involved in the operation of an EV, and the user preferences like the use of the heater or cooler in the vehicle cabin (Aimsun, 2021).

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Figure 2.5: Battery Consumption Model for electric vehicles. Source: Aimsun (2021)

The limitations of the research are shown below:

- Lack of information on EVs by models sold in South Australia. In the case of Tesla vehicles, their sales distribution by model across Australia is unknown.
- The OD MASTEM data shows the distribution of trips by zone, but not the number of vehicles per zone.
- The OD MASTEM data does not provide round trips from each zone when the vehicle arrives at its final destination/home.

To overcome these limitations, a series of assumptions and calculations have been made, which are explained in the Methodology chapter. Likewise, it should be mentioned that the scope of this study is limited only to the Adelaide Metropolitan, South Australia,

3 Methodology

3.1 Number of trips in 24 hours

This study employs OD data from MASTEM V3 (2019) that is used for the Department for Infrastructure and Transport (DIT). As the MASTEM Version 3 User Guidelines explain there are:

- Four model time periods that have been developed:
  - AM peak period – 7 am to 9 am for both Highway and PT
  - Day Time period – 9 am to 4 pm for Highway and 9 am to 3 pm for PT
  - PM peak period – 4 pm to 7 pm for Highway and 3 pm to 6 pm for PT
  - Night Time period – 7 pm to 7 am for Highway and 6 pm to 7 am for PT
- 634 transport zones.

The numbers of zones are related to the "Node numbers", as seen on

Table 3.1, for the interest of this study the CBD zones and other internal zones will be used. The MASTEM OD data are the result of mathematical models of travel for four model time periods presented in four different matrices for light vehicles. Each spreadsheet is a 605x605 matrix.

Table 3.1: Foundation network node numbering schema

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Source: MASTEM Version 3 User Guidelines (2019).

The four spreadsheet used are:

- AM peak period (AM PP Cars) – 7 am to 9 am
- Day Time period (DT P Cars) – 9 am to 4 pm
- PM peak period (PM PP Cars) – 4 pm to 7 pm
- Night Time period (NT P Cars) – 7 pm to 7 am

Note that we are working with car travels information, excluding trucks and public transport.

Performing the sum of these 4 matrices, we will obtain a spreadsheet with a 605x605 matrix with the total number of trips in 24 hours from each origin to all destinations (24-hour Number of Trips Origin-Destination Matrix).

3.2 Distance between each zone

The MASTEM data also includes the shapefile of all 605 zones which is in the GDA 1994 MGA Zone 54 projected coordinate system and using the ArcGIS Pro software the boundaries of each zone can be seen in Figure 3.1.

On ArcGIS Pro, using the Calculate Geometry Attributes tool it is possible to find the centroid of each polygon (zones) (ESRI, 2019), then, having the centroids and using the geoprocessing tool called Generate Origin-Destination Links (Analysis) (ESRI, 2021), the software can calculate the distance between each centroid with its own "Attribute Table" which shows the link distance of each origin to every destination. That table is formed by 365,420 features, this is the result of multiplying 605 origins and 604 destinations, without including the origin as its destination itself.

Using the "Table to Excel" geoprocessing tool, the shapefile is exported to an excel file. However, the information exported to the table will need to be converted into a matrix, using the PivotTable option. On the PivotTable Field, we need to drag the Origin data to the Columns field, the Destination Data to the Rows field and the "Distance" data to the "Values" field, the Distance will be shown as the sum of distance, however, is only one data. Finally, we obtain the 605x605, matrix distance, also we can set the PivotTable Options to show “0” for empty cells, as we know that there is no distance “from the origin to the origin”.

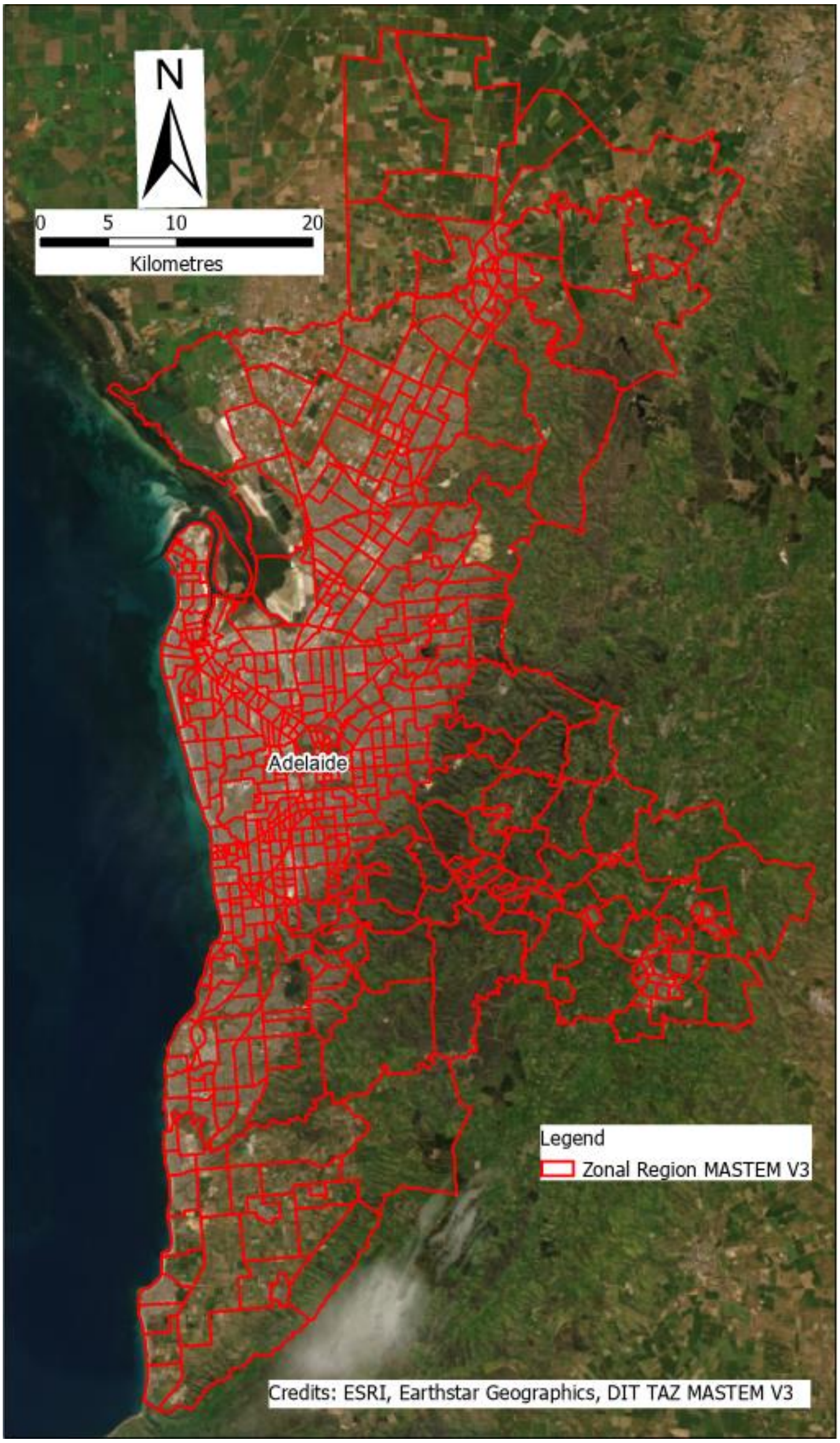

Figure 3.1: Map of Adelaide with the 605 transport zones.

3.3 Estimation of vehicle kilometres of travel (VKT)

Now, we can estimate the Vehicle Kilometres of Travel (VKT) and our first assumption will be that one travel analysed zone to all other zones are round trips from each zone.

The total daily travel (the daily VKT) on each zone is the sum of the product of trips in 24 hours and the distance between zones. Multiplying the matrices from the Number of trips in 24 hours and Distance between each zone we obtain Vehicle Kilometres of Travel matrix. Then, the sum of each row is the total daily VKT of each origin zone. Note that the distance between each zone is obtained from their centroids, it can be considered as another assumption and it can be improved for future works.

These values represent the daily distance travelled of the vehicles in one zone, including departure and return home. It is saved in a spreadsheet.

3.4 Estimation of EVs sales in South Australia

There was no information on EVs models sales in South Australia and we estimate them from two different sources. The first is from the National Transport Commission (NTC) which use data from the Federal Chamber of Automotive Industries (FCAI) and the second is from the information provided by [Content removed for privacy reasons].

The first information allows us to know the national sales and the total sales in South Australia. In Figure 3.2 it can be seen that Tesla sold 2,950 vehicles and all other makes sold 2,925 across Australia and it is possible to estimate that South Australia's sales were 97 Tesla vehicles and 413 all other carmakers.

The second information in Table 3.2 confirms that 2,925 EVs were sold across Australia, although the most important piece of information is which EVs models were sold. Note that there is no information about Tesla's model sales.

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Figure 3.2: Total EV sales across Australia 2019. Source: NTC (2020)

Table 3.2: Australian EVs Sales, December 2019

Model	Units
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Source: [Content removed for privacy reasons] (2020)

Finally, we can obtain the proportion for South Australia sales. In Table 3.3, it is possible to see that there were 510 EVs sold in South Australia.

Table 3.3: South Australian EVs sales, December 2019

Model	Units
Mitsubishi Outlander	99
Tesla	97
Hyundai Kona Elite	70
Hyundai Ioniq Electric Elite	67
Nissan Leaf	58
Porsche Cayenne E-Hybrid	38
Jaguar I PACE	22
BMW i3	14
Volvo XC60 T8 Polestar Engineered	12
Volvo XC90 T8	5
MINI Countryman	5
Renault Kangoo MAXI	4
Land Rover Range Rover Sport	4
BMW 5 Series	3
BMW i8 Coupe	2
Volvo S60	2
BMW X5	2
Mercedes Benz EQC	2
Mercedes Benz C300e	1
Renault Zoe Intens146	1
Land Rover Range Rover	1
Volvo V60	1
Total	**510**

3.5 Estimation of average EV Energy Consumption (Wh/km)

The energy consumption of EVs can vary during the trips, depending on the needs and skills of the driver, factors as climate control, navigations systems, speed, brakes can make it double the energy consumption indicated in the technical specification of the EV (Evtimov, et al., 2017).

For the purposes of this thesis, we worked with the specified values according to the information from the Green Vehicle Guide website (2021). The data is based on laboratory tests under controlled conditions and may vary according to the circumstances of how the vehicle is operated (Green Vechicle Guide, 2021) and we complete Table 3.4.

Table 3.4: EV Energy Consumption in Wh/km

Car Maker	Number of Vehicles	Energy Consumption Single Vehicle	Energy Consumption Total Car Maker
Mitsubishi Outlander	99	161	15,939
Tesla	97	188	18,236
Hyundai Kona Elite	70	143	10,010
Hyundai Ioniq Electric Elite	67	117	7,839
Nissan Leaf	58	180	10,440
Porsche Cayenne E-Hybrid	38	209	7,942
Jaguar I PACE	22	230	5,060
BMW i3	14	141	1,974
Volvo XC60 T8 Polestar Engineered	12	178	2,136
Volvo XC90 T8	5	182	910
MINI Countryman	5	152	760
Renault Kangoo MAXI	4	155	620
Land Rover Range Rover Sport	4	210	840
BMW 5 Series	3	176	528
BMW i8 Coupe	2	119	238
BMW X5	2	257	514
Volvo S60	2	255	510
Mercedes Benz EQC	2	214	428
Mercedes Benz C300e	1	157	157
Renault Zoe Intens146	1	133	133
Land Rover Range Rover	1	157	157
Volvo V60	1	182	182
Total	**510 units**		**85,553 Wh/km**

Therefore, the estimated average of EV Energy Consumption in the South Australia fleet is obtained from the followed equation:

$$Average\ EV\ Energy\ Consumption = \frac{Total\ of\ Energy\ Consumption}{Total\ Number\ of\ Vehicles} \qquad (1)$$

The average EV Energy Consumption in South Australia is 168 Wh/km

3.6 Estimation of average Battery Capacity (kWh)

EVs are powered by electric batteries which have their weight, type, size, capacity, specific energy, and cycle life (Manzetti & Mariasiu, 2015). In this section, the average capacity storage will be estimated from the vehicles in the South Australian market (2019) as can be seen in Table 3.2. The battery capacity of each vehicle was obtained from Appendix 2: Electric Vehicle model availability of the Electric Vehicle Council Report (2020) and the results can be appreciated in Table 3.5.

Table 3.5: EV Battery Capacity in kWh

Car Maker	Number of Vehicles	Battery Capacity Single Vehicle	Battery Capacity Total Car Maker
Mitsubishi Outlander	99	14	1,366
Tesla	97	75	7,275
Hyundai Kona Elite	70	64	4,480
Hyundai Ioniq Electric Elite	67	28	1,876
Nissan Leaf	58	40	2,320
Porsche Cayenne E-Hybrid	38	18	680
Jaguar I PACE	22	90	1,980
BMW i3	14	42	588
Volvo XC60 T8 Polestar Engineered	12	12	139
Volvo XC90 T8	5	12	58
MINI Countryman	5	10	48
Renault Kangoo MAXI	4	33	132
Land Rover Range Rover Sport	4	13	52
BMW 5 Series	3	13	39
BMW i8 Coupe	2	12	23
BMW X5	2	24	48
Volvo S60	2	12	23
Mercedes Benz EQC	2	80	160

Mercedes Benz C300e	1	14	14
Renault Zoe Intens146	1	41	41
Land Rover Range Rover	1	13	13
Volvo V60	1	12	12
Total	**510 units**		**21,368 kWh**

Source: Electric Vehicle model availability of the Electric Vehicle Council Report (2020)

Therefore, the estimated average EV Battery Capacity in the South Australia fleet is obtained from the followed equation:

$$Average\ EV\ Battery\ Capacity = \frac{Total\ of\ Battery\ Capacity}{Total\ Number\ of\ Vehicles} \quad (2)$$

The average EV Battery Capacity in South Australia is 42 kWh.

3.7 Confidence interval: Lower & Upper boundary

Any traffic studies and surveys need a correct analysis to present the results. To report statistical results, they must be framed with terms of percentage error and confidence interval. Because the analysed sample represents a part of the larger target population, a risk factor that the sample is not representative of must be specified. Typically, a risk of 1 in 20 chances (sample) is taken, which becomes to the "95% confidence interval" (Austroads, 2013).

A 95% error bound on $\bar{X}$ will no differ from μ by more than $\pm 1.96\sigma_{\bar{X}}$ (Panik, 2012). Therefore, the Confidence Interval is equal to the mean $\pm$ error bound and it can be seen in Table 3.6.

Table 3.6: Mean, Lower and Upper Boundary for Energy Consumption and Battery Capacity of EVs

	Energy Consumption (Wh/km)	Battery Capacity (kWh)
Lower Boundary	151	32
Mean	168	42
Upper Boundary	185	52

3.8 Registered vehicles by postcode

This information was obtained from the Data SA website (2020), the data date used was the 30 June 2020. That database has all types of vehicles registered, the types selected were panel van, sedan, station wagon, taxi, taxi-wagon, utility, van vehicle. All this information is related to the field Owner Postcode.

The shapefile of the South Australian suburbs boundaries was obtained from the Data SA website (2020) and it was open into ArcGIS Pro. Aid by Dissolve (Data Management), a geoprocessing tool, it was possible to combine the different suburbs that belong to the same postcode.

Because there are many postcodes a new shapefile was created only with the suburbs that intersect the MASTEM Zones. These postcodes through the Add Join geoprocessing tool were assigned the number of vehicles found in the previous step.

The result can be seen in Figure 3.3 and it can be clearly seen that postcodes' boundaries do not match with the MASTEM Zones.

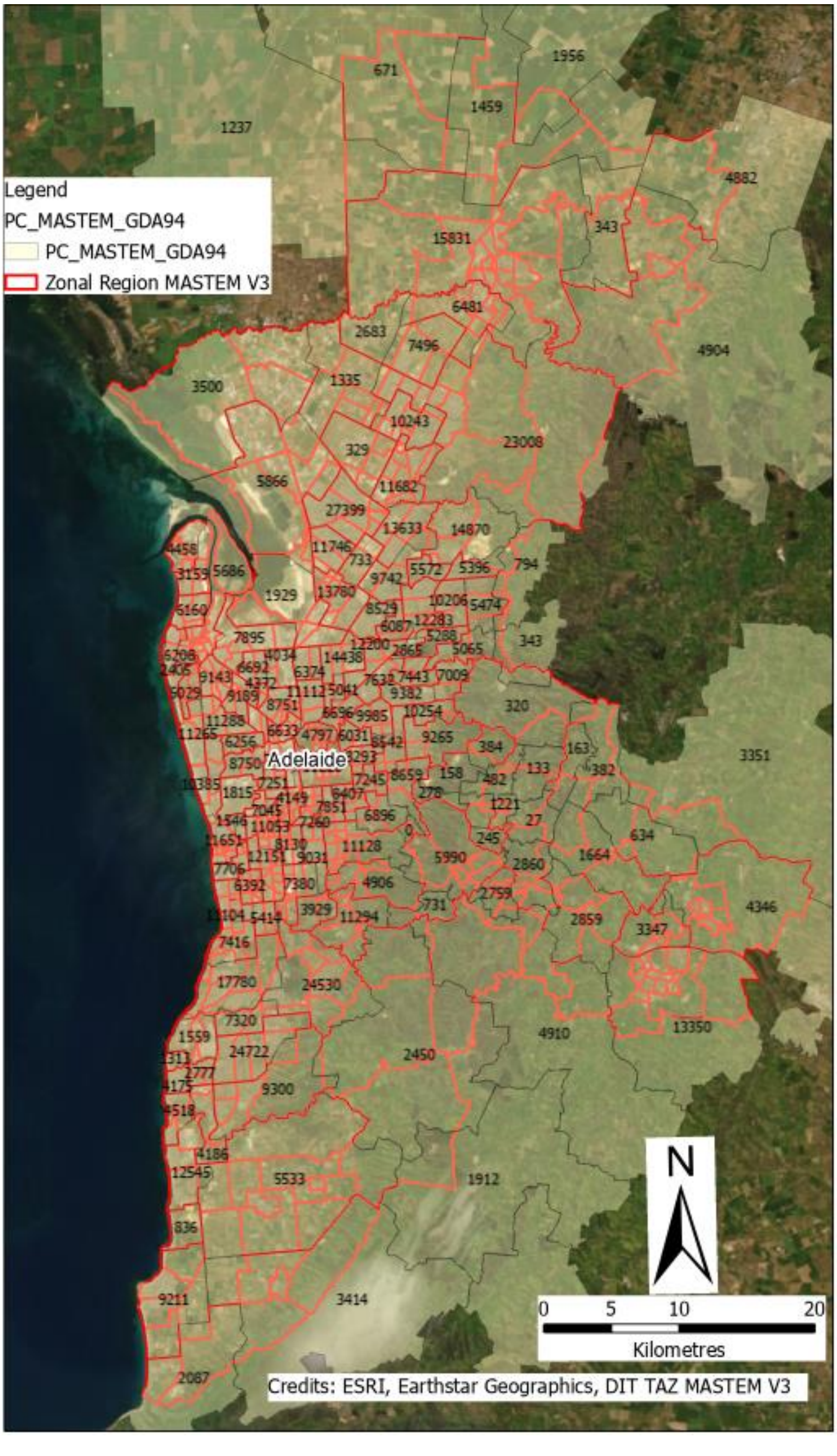

Figure 3.3: Postcodes with the number of vehicles and the MASTEM Zones.

3.9 Vehicles by MASTEM Zones

As we need to know the number of vehicles by MASTEM Zones, it is necessary to transfer the information from the postcodes into the MASTEM Zones. A MASTEM zone can be part of a postcode boundary and can also be made up of multiple postcodes. Nor can the vehicles be distributed proportionally to their areas because they are distributed according to points of concentration in each postcode. For example, postcode 5502 may have 1,237 vehicles, however, its highest concentration of vehicles is outside the MASTEM Zones, therefore the contribution of vehicles to the MASTEM Zones is lower.

To accomplish this task, it was necessary to use the geolocated cadastre shapefile of each property within South Australia, the shapefile was obtained from Flinders University's Server (2020). Aid by the Spatial Join geoprocessing tool matching "Have their center in" (From their centroids) it was possible to estimate which postcode they belong to. By doing this it was also possible to address the number of cadastre boundaries in each postcode. Now, we can estimate the number of vehicles per cadastre by dividing the number of vehicles by the number of cadastres per postcode.

A new shapefile was created selecting by location with only the cadastre boundaries that belong to the analysed postcodes (564,164 features). Then we could see that only 551,060 features belong to the MASTEM Zones.

Again, we use the Spatial Join geoprocessing tool matching "Have their center in" to join into our cadastre information about the Node Code (MASTEM Zone) they belong to.

Using the Dissolve (Data Management) geoprocessing tool, it was possible to combine the different cadastre that belongs to the same MASTEM Zone. Also, by doing this it was possible to sum the number of vehicles per each of the 605 zones. The result can be appreciated in Figure 3.4.

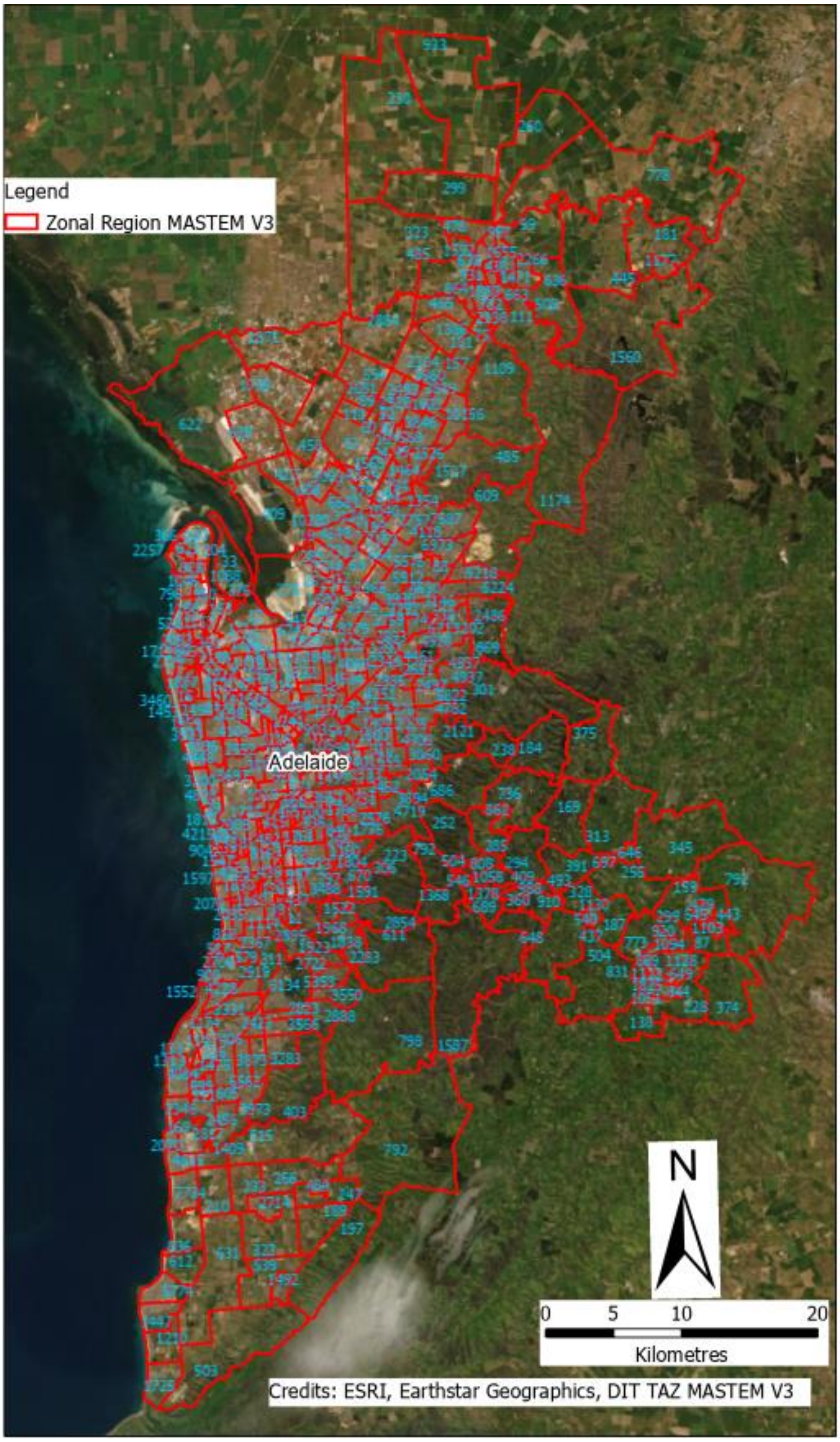

Figure 3.4: Map of Adelaide with the 605 MASTEM Zones and number of vehicles.

3.10 Energy Remaining in EVs

The number of vehicles by MASTEM zones in ArcGIS was exported to an excel file, then the number of vehicles were linked with the spreadsheet from chapter 3.3 Estimation of vehicle kilometres of travel (VKT).

Using Excel and taking the VKTs and the number of vehicles in each zone, we proceed to calculate:

1) The total Energy Storage per zone (kWh), multiplying the number of vehicles by the Battery Capacity.
2) The energy used by all the vehicles in each zone, multiplying the VKT by the Energy Consumption.
3) The remaining energy is calculated by the difference between the total Energy Storage per zone and the energy used by all vehicles in each zone.
4) In ArcGIS Pro, using the "Join Table" processing tool, we join the results above to the MASTEM Zones shapefile. By doing this, the data is joined temporally, using the "Copy Features" geoprocessing tool is possible to make it permanent and a new feature class (shapefile) is created.

These four steps were repeated for the three scenarios: the mean, the lower and upper boundaries. Hence, we obtain 3 different spreadsheets and 3 shapefiles.

To display them graphically, it was considered to create a list of all the Remaining Energy values of the 3 scenarios, the list was sorted in ascending order and divided into 10 equal parts. In other words, we obtained the rank of each value of the total data set as a percentage, by doing this we can obtain the range of the 10 percentile groups. This range of 10 classes was used for the symbology in ArcGIS Pro, which is the same legend for each scenario map.

3.11 Number of vehicles in each scenario

As we obtain the percentile range in the chapter above, in excel is possible to calculate the vehicles in each scenario, to accomplish this we follow the next steps:

1) In Excel, on the previous spreadsheet we have the “Energy Remaining” column with all the values (3 scenarios) sorted in ascending order, next to them we create the “Rank” column, in each entry, we insert the PERCENTRANK.INC formula where the array data is the total list of the column “Energy Remaining”, the value we want to know the rank is the value of the same row and the significance is 1 because we want just one digit. Using that formula, we obtained the rank values of 0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0. As the data is in ascending order, the rank values are also in ascending order.
2) For each spreadsheet of Energy Remaining in EVs (mean, lower boundary and upper boundary) in the column next to the values of “Energy Remaining”, we insert the VLOOKUP formula to find the rank value found in the spreadsheet above.
3) Then we can create a new spreadsheet and use the SUMIFS formula to know the number of vehicles for each range for the three scenarios and as we know the total vehicles, we can calculate the percentage of the vehicles that correspond to each range of percentile.

3.12 Estimation of Electricity Consumption in South Australia

The Australian Bureau of Statistics estimated that 1,770,790 people were living in South Australia as of 30 December 2020 (Plan SA, 2021) and having the electricity consumption benchmarks for Adelaide and environs shown in Table 3.7 sourced from Frontier economics (2020) we can calculate the annual average of electricity consumption in Table 3.8 depending on the household size.

To estimate the average consumption per one person, we use the values for household sizes of 1 to 4 people, the sum of electricity consumption was 58 kWh and then we divided by 10 people (the sum of the household size of 1, 2, 3 and

4) to obtain the daily average consumption of one single person in Adelaide and environs.

Table 3.7: Adelaide and environs: Electricity consumption benchmarks (kWh)

Removed due to copyright restriction.

Source: Frontier Economics (2020)

Table 3.8: Daily average of electricity consumption (kWh) in Adelaide and environs.

Household size	Electricity consumption
1	8
2	14
3	17
4	19
5+	24

3.13 Distribution of driving distances

For a better understanding of the distribution of trips, it was required to make a histogram of the VKTs in each area from the VKT Matrix. This allowed us to recognize the pattern of VKT in each area.

For example, in Figure 3.5 is possible to appreciate the distribution of the driving distances from Zone 289 (Origin) to the other 604 zones (Destination), the origin zone is around Postcode 5034 and approximately 4 km to the South from Adelaide CBD. It can be appreciated most of the VKTs are less than 26 kilometres, it represents almost 60% of the travel, which means those travel are relatively close to the origin.

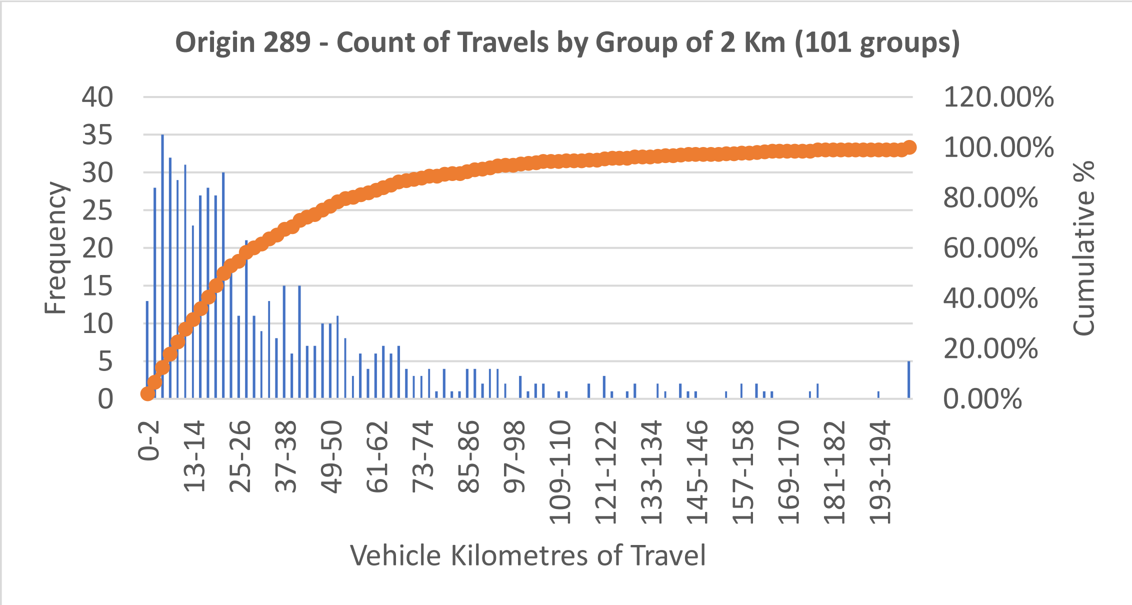

Figure 3.5: Histogram of distribution of VKT from Zone 289 to all other zones

Another example can be appreciated in Figure 3.6, which shows the VKT from Zone 214, which is around Postcode 5108, it is about 18.5 km from Adelaide CBD and just 28% of travel are no more than 8 km far. The 60% of the Driving Distances are up to 60 Km. Hence, the vehicles in this area are travelling long distances.

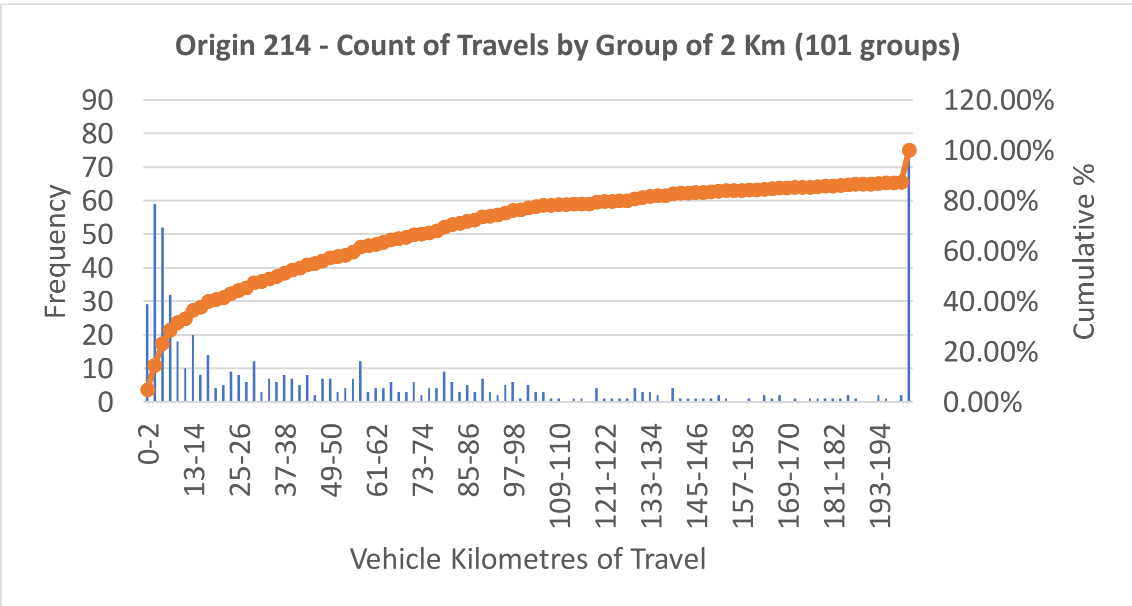

Figure 3.6: Histogram of distribution of VKT from Zone 214 to all other zones

4 Results

This chapter will show the results that were obtained with the methodology shown.

The first part of the results shows the potential storage capacity of EVs after 24 hours for the three scenarios: the lower boundary, the mean, and the upper boundary. These boundaries are based on the 95% confidence intervals developed in Chapter 3.7.

The results are shown on maps obtained through ArcGIS Pro with the data obtained from chapter 3.10. The potential storage capacity after 24-hour maps is displayed by percentile rank of total energy storage. This potential storage capacity is the remaining energy in all EVs batteries that belong to the same MASTEM Zone after 24 hours. Every polygon in the map represents each 605 MASTEM zone. Figure 4.1 shows the lower scenario, Figure 4.2 shows the mean scenario, and Figure 4.3 shows the upper scenario.

The percentile rank of total energy storage varies from red to green, where red is the lowest percentile, green is the best percentile. In the legend we can appreciate the range of the energy storage by zone after 24 hours, where:

- Range -24,375 - 2,911 represents the rank 10%
- Range 2,911 - 12,150 represents the rank 20%
- Range 12,150 - 19,561 represents the rank 30%
- Range 19,561 - 27,258 represents the rank 40%
- Range 27,258 - 37,043 represents the rank 50%
- Range 37,043 - 50,202 represents the rank 60%
- Range 50,202 - 68,639 represents the rank 70%
- Range 68,639 - 93,767 represents the rank 80%
- Range 93,767 - 138,673 represents the rank 90%
- Range 138,673 - 490,559 represents the rank 100%

For example, the rank 100% represents the tenth part of all the values with the best values and the rank 10% represents the tenth part with the lowest values.

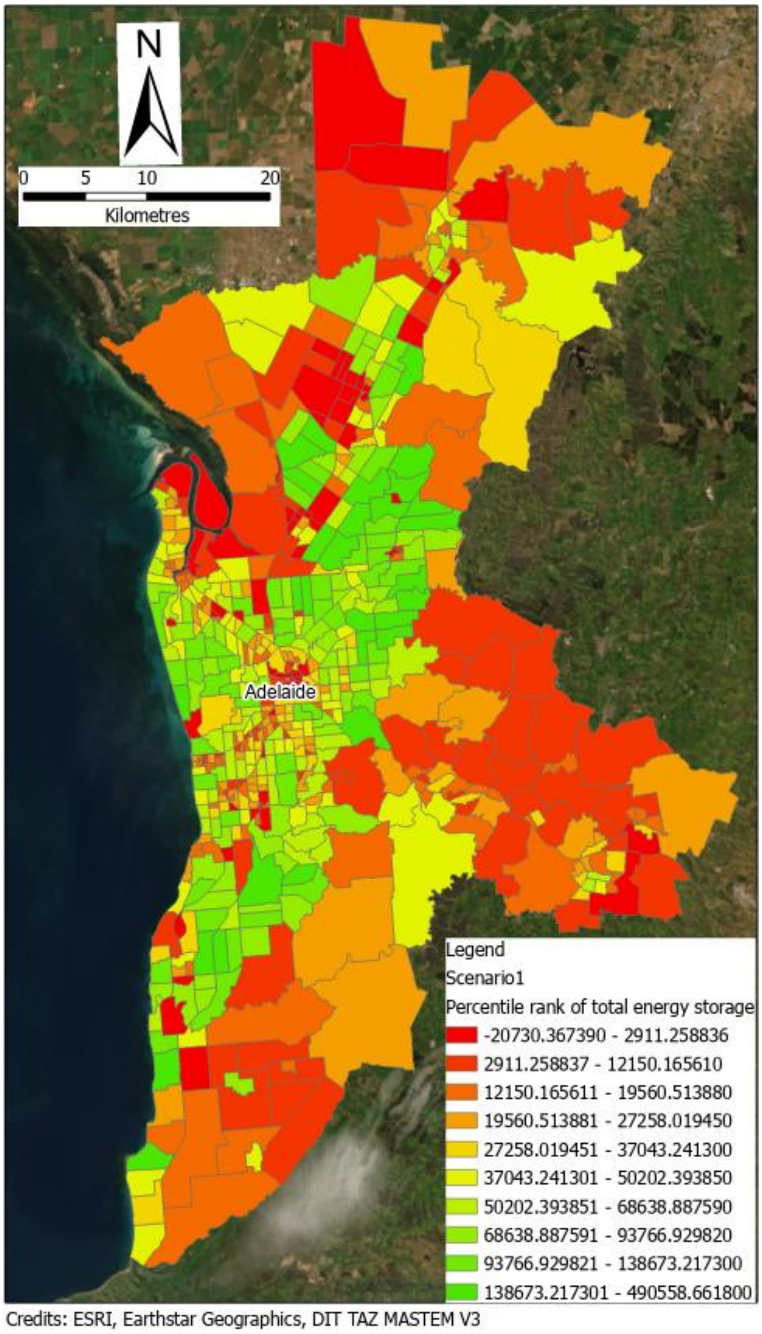

Figure 4.1: Scenario 1: Map of potential storage capacity after 24-hours by percentile rank of total energy storage.

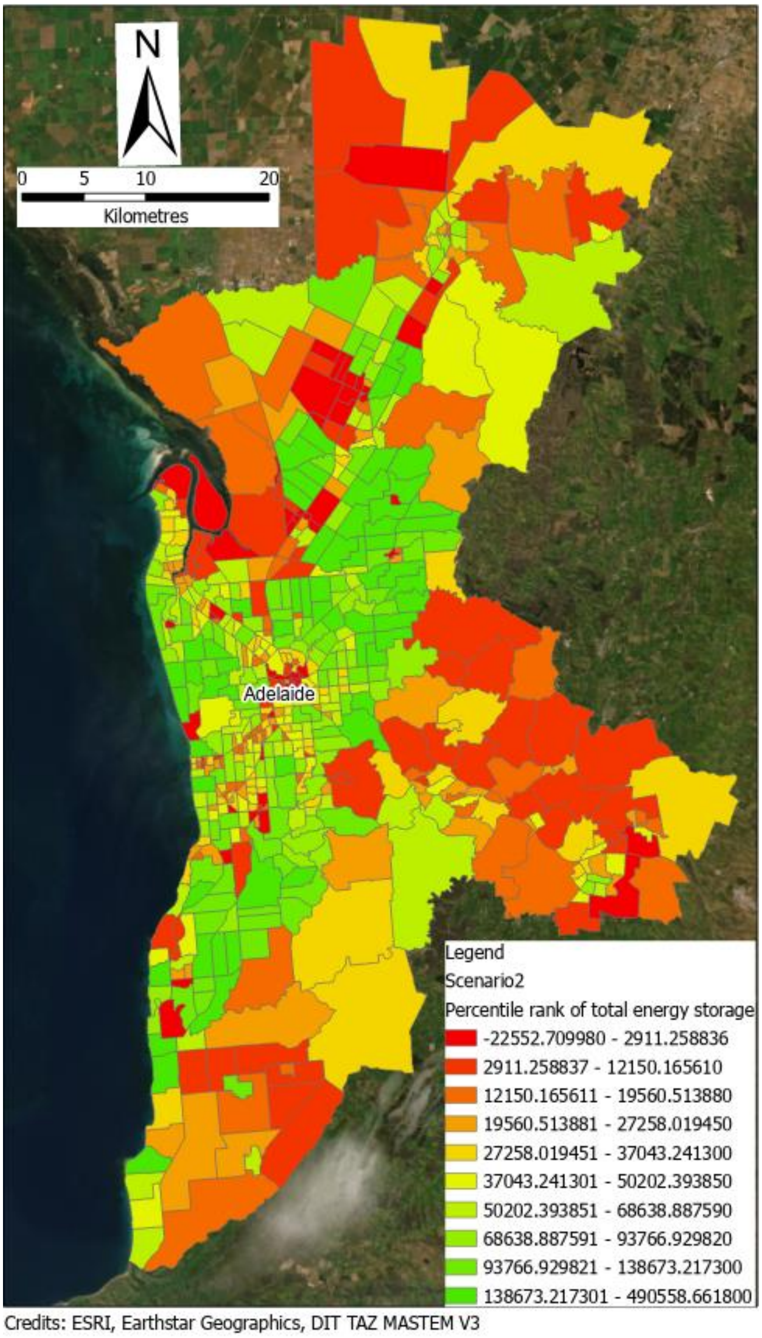

Figure 4.2: Scenario 2: Map of potential storage capacity after 24-hours by percentile rank of total energy storage.

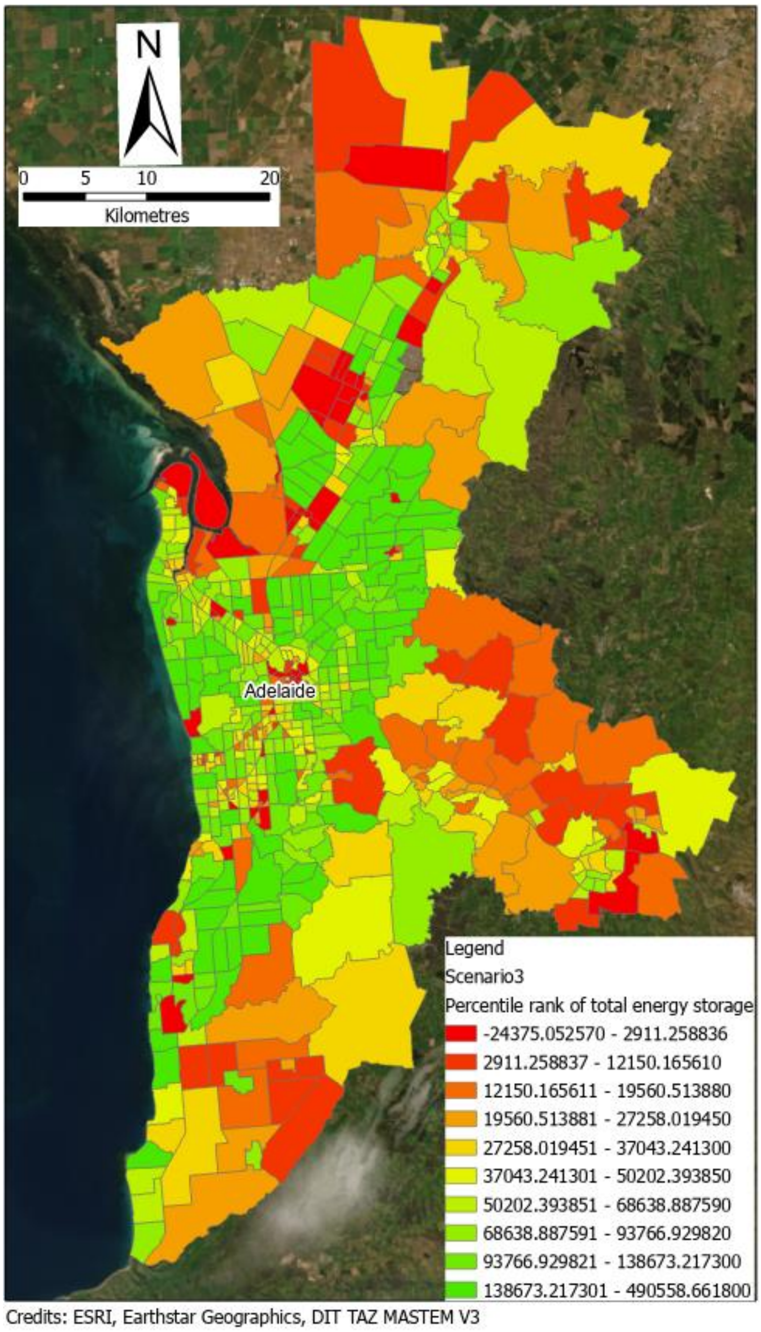

Figure 4.3: Scenario 3: Map of potential storage capacity after 24-hours by percentile rank of total energy storage.

The data from the three figures above were tabulated according to the same rank of the maps. The values are shown in Table 4.1, only positive values were considered because the remaining energy values are displayed.

Table 4.1: Percentile rank of potential energy storage capacity after 24-hours.

Range	kWh / Lower B.	kWh / Mean	kWh / Upper B.
-24,375 - 2,911	31,751	23,157	20,708
2,911 - 12,150	612,900	479,773	326,804
12,150 - 19,561	1,302,288	914,880	654,769
19,561 - 27,258	1,601,141	1,403,426	1,199,583
27,258 - 37,043	1,859,041	2,030,562	1,914,422
37,043 - 50,202	2,873,402	2,550,094	2,500,565
50,202 - 68,639	3,222,370	3,949,693	3,500,148
68,639 - 93,767	4,300,930	4,464,729	5,766,152
93,767 - 138,673	5,244,259	7,238,527	8,151,523
138,673 - 490,559	5,511,968	12,441,763	20,402,562

Table 4.2 shows the summarize of the table above, it is possible to appreciate the total of energy in each scenario.

Table 4.2: Total energy storage (kWh) in each scenario.

Lower boundary	Mean	Upper boundary
26,560,050	35,496,603	44,437,236

The total of analysed vehicles can be obtained since chapter 3.9, the present study is working with 933,058 vehicles and Table 4.3 shows the distribution of how many vehicles are in each range and shows the percentage it represents of the total vehicles for each scenario.

Table 4.3: Percentile rank by the number of vehicles and percentage in each scenario.

Range	Veh. (%) / Lower B.	Veh. (%) / Mean	Veh. (%) / Upper B.
-24,375 - 2,911	7,657 (1%)	5,327 (1%)	4,346 (0%)
2,911 - 12,150	24,854 (3%)	15,912 (2%)	9,199 (1%)
12,150 - 19,561	48,414 (5%)	25,455 (3%)	15,233 (2%)
19,561 - 27,258	58,192 (6%)	38,653 (4%)	26,315 (3%)
27,258 - 37,043	65,573 (7%)	54,738 (6%)	42,078 (5%)
37,043 - 50,202	101,370 (11%)	67,173 (7%)	52,990 (6%)
50,202 - 68,639	111,342 (12%)	104,075 (11%)	73,711 (8%)
68,639 - 93,767	148,945 (16%)	115,686 (12%)	120,688 (13%)
93,767 - 138,673	180,213 (19%)	187,993 (20%)	169,128 (18%)
138,673 - 490,559	186,499 (20%)	318,045 (34%)	419,371 (45%)

Finally, Table 4.4 shows the population of South Australia, the electricity consumption per day and the estimation of how much energy South Australia consumes.

Table 4.4: Estimation of electricity consumption (kWh) in South Australia by one day.

Population	Electricity consumption	Total
1,770,790	5.8	10,270,582

5 Discussions

- As we can see in Figure 4.1, Figure 4.2, Figure 4.3 there are some MASTEM Zones with negative values. This means that the vehicles in those zones have longer VKTs than the average battery capacity found in this project.
- MASTEM zones in the lower percentile are mostly found in places far from the city centre, in the surroundings. Other areas with negative values are characterized by containing less than 100 vehicles and are usually areas with a greater proportion of green areas. This is because the OD survey considers a large number of trips for these areas, which is not related to the number of vehicles in the zone. For the purposes of this study, negative values were excluded from the potential energy that can be stored.
- Although it is not easy to appreciate the difference between the lower (Figure 4.1) and upper limits (Figure 4.3). Table 4.2 shows us that there is a difference of 26,560,050 and 44,437,236 kWh respectively, which is 67% more energy in the upper scenario.
- The total of analysed vehicles used was 933,058 vehicles, although the Motor Vehicle Census from 2021 revealed that South Australia has 1,477,899 vehicles registered (Australian Bureau of Statistics, 2020). The number of vehicles used in this project is 63.13% of the total vehicles registered in South Australia. This is due to the limits of the project are the MASTEM Zones area, this is the Metropolitan Adelaide and environs (see Figure 3.1: Map of Adelaide with the 605 transport zones.)
- Table 4.1 shows that the best ranges (coloured in green) contain a large amount of energy comparing the lower boundary with the upper one, in the best percentile (Rank) it can be observed that the energy in the upper boundary is almost 4 times higher than the lower one, this is because to the upper scenario has better Energy Consumption and better Battery Capacity.
- Table 4.3 shows the number of vehicles in each percentile per each scenario. In this case, compared to the statement above, the numbers of vehicles with the best percentile in the upper scenario only doubled those

of the lower limit. This means that just by doubling the vehicle fleet, the energy potential has quadrupled. This can be explained because the energy consumption, as well as the batteries capacity, have better performance.

- For the present investigation, the distributions of vehicles models in South Australia were not available, which is why an estimate was made based on the methodology explained in chapter 3.4 of this investigation.
- The average Energy Consumption of EVs was obtained from the Green Vehicle Guide (2021). Those values were taken under controlled conditions by the Green Vehicle Guide (2021) and they can be reduced depending on the conditions in which the vehicle is driven such as speeding, frequent braking, with the heater or cooler, among others (Evtimov, et al., 2017).
- The average Battery Capacity calculated in the present study was 42 kWh which is below the range estimated by the Global EV Outlook (2020) which is between 48 kWh and 67 kWh. This can be due to the models in the South Australian market. This means that the capacity can improve in the coming years due to the new technologies and also if the market offers more EV models variety.
- Table 4.4 estimates the energy consumption of the South Australian population in 24 hours, it is possible to see that the energy needed is 10,270,582 kWh and compared with Table 4.2 it is observed that the lower boundary has sufficient capacity to provide energy (26,560,050 kWh).
- The estimation of electricity consumption per one single day in South Australia could be covered by the lower scenario of energy stored. Nevertheless, an evaluation for more days should be considered, since in many circumstances the user cannot charge the vehicle every day.
- OD distances were calculated between the centroids of each MASTEM Zone; however, this distance can be a limitation and it can be optimized with the real distance travelled by a vehicle on the South Australian road network. Also, the distance between the travels in the same zone (internal trips) was not included in this project.

- We assume that the number of trips in 24 hours obtained from the MASTEM database are round trips from each zone.

6 Conclusions

- Using transport modelling is possible to analyse EV battery consumption and addressing the VKT we can estimate how much charge would be left in the EV batteries to find the potential in EVs to be part of a VPPs. By doing this we can reduce the gap between the Transport and Energy sector.
- Although the average battery capacity by the Global EV Outlook (2020) is between 48 kWh and 67 kWh. The value found for South Australia in this study was between 32 kWh and 52 kWh.
- This study is based on the OD data in 24 hours and did not contemplate the analysis longer than 24 hours.
- The EVs must be recharged during periods of low energy demand, therefore they must be charged when there is greater production of solar energy in the Rooftop PV.
- VPPs use a variety of energy sources and and are controlled by electricity demand. Users of VPPs will be able to use the energy stored in their EVs during peak hours (high demand) and will even be able to share the unused energy with the members of the community, so they can generate economic income. VPP provides intertwining of multiple sources concentrated in one area, similar to the areas in the MASTEM Zones.
- It was observed that MASTEM Zones in the best quantiles have the highest concentration of vehicles which will generate more energy.
- The potential energy storage capacity is higher in the upper scenario, this is because the data entered for Energy Consumption and Battery Capacity are higher. As technology advances and more EVs models enter in the South Australian market, these values will have a better performance.
- Renewable electricity offers a series of advantages compared to conventional power plants. It is necessary to take action against climate change and EVs have the potential to help in this target. Shifting from fossil

fuel combustion engines to electric transport, EV will not create pollution as fuel combustion engines and on the contrary, it will deliver clean energy and boost the electric grid of South Australia or anywhere on the planet.

- Although, negative values were not taken into account in the calculations, these could be a project limitation, but it is estimated that these values do not affect the results as these cases occur in MASTEM Zones with small number of vehicles and it does not have a greater impact on the results.
- We are now in a transition, both in paradigms in terms of the energy use and the development of policies increasingly focused on environmental care, as well as in the manufacture and application of new materials in the near future to meet the energy needs of the society.

7 Future Work

- This report used the Origin-Destination Distance between the centroid of each MASTEM zones. In future works it would be interest to analyse the real distance a vehicle would travel on the South Australian road network.
- Negative values were found in stored energy, these values were not included in the results of this investigation. It is recommended to do studies on a smaller scale to have a better understanding.
- The average energy consumption of EVs was taken under controlled conditions by the Green Vehicle Guide (2021). It can be reduced depending on the conditions in which the vehicle is driven.
- Aimsun can use a microscopic model to analyse the energy consumption in specific zones and compare the results estimated in this study.
- The Energy Remaining in EVs could be analysed for scenarios greater than 24 hours.
- For future work, it is recommended to analyse battery cycle life to determine battery wear and performance at high repetitions of charge and discharge.

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