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Developing Tools for Modelling Electric Vehicle Charging in High-Rise Buildings

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EXECUTIVE SUMMARY

Working with Wattblock, an energy conscious company that gives assists high-rise buildings in energy reducing projects, the aim of this project was to develop a tool to assess the energy use and financial cost of implementing an electric vehicle charging system. The requirements of the tool were to be simple to operate, eliminating the need for a professional assessment, and cover the different types of charging systems available.

To achieve this aim the need was seen to develop four tools to cover all scenarios that Wattblock encounter. The aim was refined to two objectives:

- Use Microsoft Excel to model the electrical consumption of managed and unmanaged electric vehicle charging systems.
- Use Microsoft Excel to develop a calculator for estimating the cost of installation of an electric vehicle charging system in a high-rise building.

Research was undertaken to identify necessary information that affects the development of the models. These were the types of electric vehicles and charging systems available in Australia, the driving patterns of vehicles owners and the factors affecting the cost of installing a charging system.

With the research complete the development began with the basic charging model. This model was designed with simplicity in mind and only required information from the client's electricity bill to be entered. The outputs were also simple, giving a value for the unused power during off-peak periods and maximum number of vehicles that can be charged using both managed and unmanaged charging systems.

The next two tools developed went deeper into the modelling of managed and unmanaged charging systems by simulating the charging rates over time. These models also allowed for individual vehicle parameters to be used. The results from these models were also more detailed. Using graphical representations of the charging process allowed detailed information to be displayed in an easily readable format.

The final tool developed was the installation cost calculator. This tool endeavoured to estimate the cost of installing an electric vehicle charging system, based a number of key factors. There was not sufficient historical data on previous installations in high-rise buildings to make this calculator effective, so the decision was made to allow for future data to be entered and the accuracy refined over time.

To conclude the project the first three tools, the vehicle charging models, were used in three case studies to demonstrate their functionality. The results were evaluated and the conclusion was drawn that the models were useful. However as the tools developed here were for use in future scenarios and no existing electric vehicle charging system have been installed after Wattblock's advice so it was difficult to assess their accuracy.

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Special thanks Scott and Morgan from the Brisbane branch of Wattblock for the opportunity to undertake the project and their ongoing support. I gained a new understanding of the potential for energy savings in a range of scenarios and the role of technology in achieving these savings. I also had the opportunity to see firsthand the process and hard work that goes into developing a start-up company.

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1 INTRODUCTION

Recent emphasis around the globe on reducing greenhouse gas emissions has people looking for environmentally friendly alternatives to petrol and diesel cars. The increased interest in electric vehicles has led to major car manufacturers investing in research and production of Electric Vehicles. Currently there is a modest selection of Battery Electric Vehicles and Plug in Hybrid Electric Vehicles available to purchase in Australia.

When used for commuting and personal use EVs require charging on a nearly daily basis. In a residential dwelling with a single owner, installing an Electric Vehicle Charging System (EVCS) is simple. However in strata buildings installation is more complex. 'Strata Title' is a term used in property management to represent a building that contains a number of defined lots owned by individuals and common areas owned by everyone, the most familiar example is a high-rise apartment building. Strata buildings are managed by an Owners Corporation.

The car parks in strata managed buildings, often underground, are part of the common property. This means although a resident has an allocated parking spot, they are not able to make any modifications without approval from the Owners Corporation. Installation of EVCS becomes a headache for both residents and Owners Corporations.

Wattblock's goal is to help residential buildings improve their energy efficiency and reduce their energy costs by offering an alternative to an energy audit. Energy Audits are a costly and time consuming process usually undertaken by large companies to reduce their environmental footprint and reduce energy costs. The high costs can make energy audits inaccessible to residential buildings. Wattblock overcomes this by using data aggregation and analytics to provide a quick assessment and report containing potential energy saving projects.

In the future Wattblock sees the need to include advice on implementing electric vehicle charging systems in their reports, including advice on cost, maintenance and energy consumption. The aim of this project was to develop tools to model electricity consumption when charging electric vehicles. These models needed to be adjustable for use by Wattblock on a case by case basis. In addition to the models, a calculator was to be developed to receive historical data and use this data to estimate the cost of installing an electric vehicle charging system. Again this calculator was designed to be used on a case by case basis as Wattblock acquires new clients. The development of these tools ensures advice given by Wattblock has a solid engineering basis.

To develop even a basic model of the electrical consumption, it was necessary to recognise charging systems fall into two categories. The first is an unmanaged system where a vehicle plugged in to a charging station starts charging immediately, if a second is plugged in both are now charging. This system is simple however the number of vehicles that can be charged simultaneously is limited by the power supplied to the building. The second type of charging system overcomes this problem by using a central unit to control the power sent to each vehicle being charged. Even if a large number of vehicles require charging the building's power limit will not be exceeded. The central control unit can direct the available power to

each vehicle as needed. In the process of completing the project a model was made for each type of charging system.

In addition to the models for charging electric vehicles a calculator to estimate the cost of installing an electric vehicle charging station was also developed. This calculator identified factors that have a significant effect on the cost of installation. These factors were then used to calculate the cost of installation when approaching new buildings. As no significant statistics were found on electric vehicle charging system installation costs, this calculator was designed to use future data to increase accuracy. As information is gathered and entered into the calculator estimating the cost for future clients will become more precise.

After developing these tools three buildings were selected as case studies. The buildings were selected cover the range of the types encountered by Wattblock and to demonstrate the functionality of the developed tools.

Interest and development in the field of electric vehicles is bringing a forecast increase in electric vehicle ownership. A vehicle owner's desire to charge these vehicles at home is an important consideration for Owners Corporations in high rise buildings. The tools developed prepare Wattblock to give advice to these Owners Corporations. The simplicity of the tools allows for a quick response, and built in adjustability means the tools are applicable to a wide range of buildings.

1.1 Project Objectives

- Use Microsoft Excel to model the electrical consumption of managed and unmanaged electric vehicle charging systems.
- Use Microsoft Excel to develop a calculator for estimating the cost of installation of an electric vehicle charging system in a high-rise building.

2 LITERATURE REVIEW

2.1 Climate Change and Greenhouse Gas Emissions

Around the world climate change is the talking point from university to politics, with an emphasis on greenhouse gas emissions. Many people argue electric vehicles have a role to play in reducing greenhouse gas emissions. Internal combustion engines found in conventional vehicles emit a range of gasses that contribute to climate change and urban air pollution. These emissions contain nitrogen oxides, carbon monoxide and non-methane volatile organic compounds.

Electric vehicles do not emit any tail pipe emissions, and as such have no tail pipe. The lack of tail pipe emissions eliminates any contribution to urban air pollution however this is not the full story. In Australia the majority of electricity generated is from coal fired power stations. This means the electricity consumed by electric vehicles produces greenhouse gasses during generation. The National Greenhouse Accounts Factors report from the Australian Government Department of Environment [1] determined the National Electricity Market has an emissions factor of 0.83 kg CO₂-e/kWh. This means for every kWh of electricity produced 0.83 kg of carbon dioxide equivalent greenhouse gasses are emitted. The average efficiency of electric vehicles was found to be around 18 kWh/100km. By combining the Australian emissions factor and the vehicle's efficiency, CO₂ equivalent emissions come to 15 kg/100km. This shows that although electric vehicles have no direct emissions they still contribute to climate change.

Internal combustion engines found in conventional vehicles emit greenhouse gasses directly from the tailpipe. A comparison of the emissions can be made with electric vehicles by again referring to the National Greenhouse Accounts Factors report [1]. The report found gasoline burned in transport vehicles contained an energy factor of 34.2 GJ/kL also the emissions factor to be 67.4 kg CO₂-e/GJ. Combining these two figures with a vehicle efficiency of 8 L/100km the vehicle's emissions were 18 kg CO₂-e/100km. The result tips in favour of the electric vehicle however only by a small margin. The comparison is more difficult when considering the location within Australia. For example in Queensland the emissions factor for electricity generation is 0.79 [1], tipping the comparison further in favour of the electric vehicle. Victoria has a higher emissions factor of 1.13 [1] tipping the comparison in favour of the petrol powered vehicle.

Transitioning to an electric vehicle simply because it's better for the environment is not a strong argument in Australia. In the early stages of the project calculating the reduction in CO₂-e emissions by changing to an electric vehicle was considered for addition to the charging models. However due to the variation in the different sources of electricity it was deemed to complex and this component was not developed.

2.2 Departure from Oil

There is a stronger economic case for the use electric vehicles at the national level. In America the Electrification Coalition published a report called Electrification Roadmap [2]. This report makes the case for large scale electrification of vehicle transport. While Australia has different challenges, many of the driving factors are the same.

The most significant driving force is to reduce dependency on oil, Australia's vast size and comparatively small population means our economy depends highly on the transport sector for getting people and goods from one place to another. As of 2014 transport made up 27.3% of energy consumption in Australia, with 72.8% of that spent on road transport REF. The oil that supplies the majority of the transport sector comes from a range of countries (See Figure 1) a number of which are plagued by corruption and political instability.

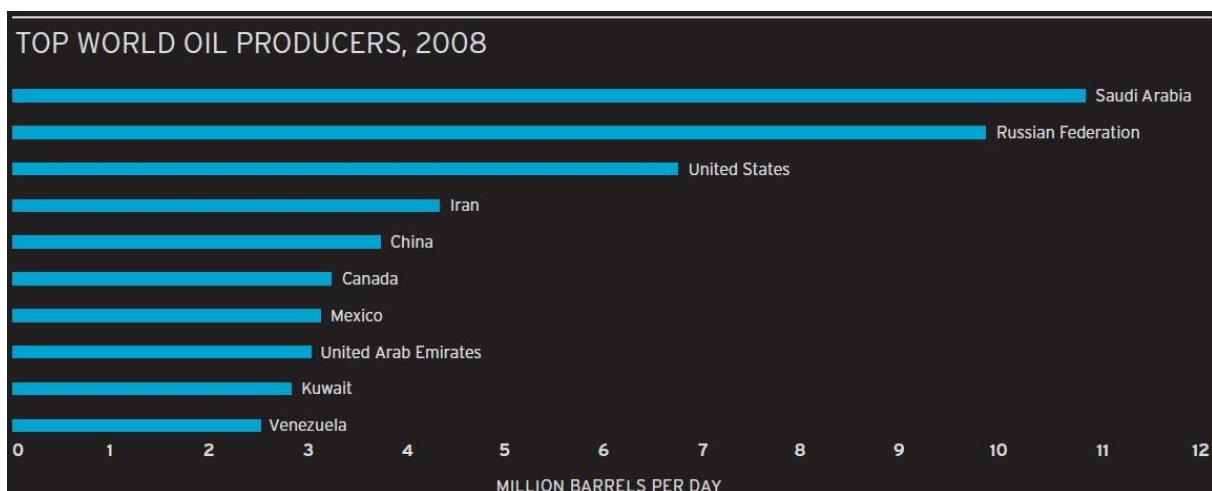


Figure 1 Source: Electrification Roadmap [2]

This instability has caused volatility in the price of oil from \$33.75USD per barrel in 2003 to a peak of \$97.26 in 2008 [2]. This caused panic in the American market and demand dropped by 8.5% in the last quarter of 2008. America has the ability to supply a large amount of its own oil demand however this is not the case for Australia. Without the same level of oil production Australia is heavily dependent on these politically unstable nations. By moving toward electricity as the energy supply for the transport sector, energy security is greatly improved. Australia is a significant exporter of coal and natural gas, and sources of renewable energies, such as wind and solar, are also abundant in Australia. While only making up a small part of our current electricity supply, renewable energy is growing. In 2014 despite Australian energy consumption dropping by 1.5%, renewables grew by 4% with solar and wind making up more than half of the growth [3]. With a range of energy sources Australia is in a prime position to shift away from imported oil and the paired volatility.

There are a number of alternatives to oil already available in Australia some of these are natural gas, biofuels and biomass. Electricity is well placed to replace oil as the fuel for the transport sector for a number of reasons. The current design of the electricity generation network focuses on the ability to meet peak demand. Peak demand only lasts a small part of the day, the rest of the time these power generation facilities are scaled back or even turned

off entirely. This leaves a large potential for electricity generation unused. Alongside the spare generating capacity, another advantage of electricity is the existing distribution network. Australia has a comprehensive transmission and distribution network already in place giving it an advantage over other oil alternatives.

With a range of alternative energy sources Australia is well placed to reduce its dependence on imported oil. Between coal, natural gas and renewables there is a range of domestic sources prime for use in generating electricity to power the road transport sector. Australia is well placed to adapt its electrical generation to supply the road transport sector and improve energy security.

2.3 High Rise Buildings

Currently Australian residential dwellings largely consist of detached housing. The makeup of new dwelling approvals in Australia over the last two decades show a steady trend away from detached housing and toward high-rise apartments. This trend has been accelerating since 2010 and new high-rise apartment approvals reached 25% in 2014 [4]. As an increasing number of people are living in multi-story apartments these buildings and their management have to make accommodations for residents that drive electric vehicles.

All high-rise buildings in Australia are overseen by an Owners Corporation. The Owners Corporation, formerly known as Body Corporate, is made up of the owners of the individual apartment in the building. Owners Corporations are responsible for all common area in the building and this includes car parking areas usually found underground. In order to make any modifications to a common area, such as installing electric vehicle hardware, individuals must obtain approval from the Owners Corporation.

Currently a common solution for charging electric vehicles in high-rise buildings consists of the resident running an extension lead from their allocated parking space to a nearby power outlet, an example of this was captured in Figure 1. This process is rarely sanctioned by the Owners Corporation and as such no process is in place to recoup electricity costs from the vehicle owner. This charging solution may also create a safety hazard with an unsecured extension lead running across vehicle thoroughfares and walkways.

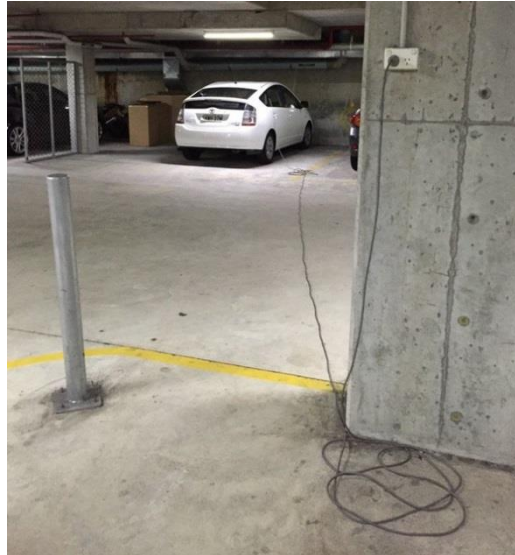


Figure 2 An example of unsafe charging

The Condominium Home Owners Association of British Columbia published a report in 2014 titled “Installation of Electric Vehicle Charging Stations on Strata Properties in British Columbia” [6]. This report outlines a number of steps Owners corporations should undertake before installing an electric vehicle charging system. A summary of these are as follows;

1. Identify suitable parking for charging location(s).
2. Determines the type of charging system necessary.
3. If parking re-allocation is deemed necessary, negotiate for re-assignment by special resolution or annual general meeting.
4. Identify the cost involved in installation of the electric vehicle charging system accounting for any electrical or other service necessary.
5. Identify any upgrades or permits that are necessary as a result of step four.
6. Seek approval for expenses incurred by the Owners Corporation at an annual general meeting or special general meeting.
7. Establish a rule to recoup electricity costs incurred by the electric vehicle charging system.

Australia shares a similar structure in the management of multi-storey apartment buildings and the process outlined is applicable here. The modelling of electric vehicle charging completed in this project assists Owners Corporations in steps 2 and 4 above, furthermore as part of Wattblock’s energy report is invaluable in seeking to gain approval in step 6. For vehicle owners approaching the Owners Corporation the process is the same with the onus on the vehicle owner to make the case for implementing a charging system.

As outlined above the process from idea to action for an Owners Corporation when implementing an electric vehicle charging system is slow and complex. Despite this complexity the need to tackle the issue is becoming a priority with the increase in electric vehicle ownership and approvals for construction of high-rise buildings. The outcomes of this project were designed to simplify the process and help individuals and Owners Corporations understand the costs involved.

2.4 Types of Electric Vehicles

At the time of writing this report there were a modest number of electric vehicles available to Australian consumers. These electric vehicles use a range of technologies ranging from Hybrid Electric Vehicles (HEV) which have no external charging ability to full electric vehicles that rely completely on external charging for energy.

The most common and widespread of the electric vehicles is the HEV thanks in large part to the Toyota Prius. Thanks in part to its early entrance to the market worldwide Toyota Prius sales passed the two million mark in 2010[6]. HEVs use a conventional internal combustion engine coupled to an electric motor in conjunction with a small battery to extract the optimum energy efficiency from their fuel source. As they are exclusively powered by petrol or diesel HEVs do not require charging. However their newer offshoot, plug-in hybrid electric vehicles (PHEVs), can charge the battery directly from a charging station. An example available in Australia is the Mitsubishi Outlander PHEV shown in Figure 3. PHEVs have the ability to travel long distances and fill up at any fuel station, in fact the batteries never need to be charged directly [7]. The major advantage over HEVs is the ability to directly charge the battery and run solely on electric power for short distances.



Figure 3 Mitsubishi Outlander PHEV [8] (left) and Tesla Model S [9] (right)

The next step after PHEVs is the full electric vehicle (EV). These vehicles rely solely on electricity for propulsion and do away with the internal combustion engine altogether. In order to travel a reasonable distance before requiring a recharge EVs require a significantly larger battery. Figure 3 shows a great example the Tesla Model S of which the top model carries a 90 kWh battery beneath the floor [9]. At the time of writing this report the cost of electric vehicles is still prohibitive for most consumers however as they are becoming more widely accepted the cost is falling.

As HEVs do not have the ability to charge externally they were not considered in this project. As the size of the batteries and the efficiency of the PHEVs and EVs affect the amount of electricity necessary for charging they were an important factor in the development of the charging models.

2.5 Electric Vehicle Charging Solutions

When looking at charging electric vehicles in a location detached from the resident's dwelling there was more than one solution. Electric vehicle charging systems fall into two categories, the first being an unmanaged solution where the charging rate is controlled by the vehicle connected to the system. The second category covers managed charging systems where the charging rate of each vehicle is controlled by a central unit. Both systems have advantages and disadvantages and as each application is different there is no best solution.

In the unmanaged solution (shown in Figure 4) each vehicle is connected to a new meter and the Owners Corporation or the energy supply company is responsible for recouping costs relating to electricity used for charging. As electric vehicle charging requires lots of power, the number of vehicles that can be charged simultaneously in this system is limited by the power available. In order to prevent overloading the system the maximum total power drawn by the connected vehicles must not exceed the determined limit, even if one or more vehicles are not charging at the current time.

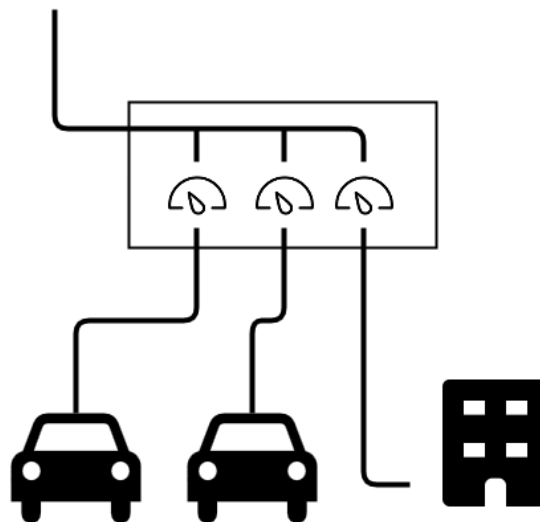


Figure 4 Layout of unmanaged charging

In cases where a small number of vehicles need charging there are advantages to the unmanaged system. A big advantage is the cost, installation cost is low as there is no need for wireless connectivity and there are no fees to be paid to a third party for charging management. Simplicity is also an advantage as electricity fees are paid directly to the Owners Corporation or the energy supply company.

The alternative category covers managed charging systems (shown in Figure 5), this type of system allows for more vehicles to be charged from a limited power supply by using a central unit to control the rate of charge of each connected vehicle. By distributing the power available amongst the charging vehicles any number can be connected without exceeding the determined limit. Also when a vehicle is finished charging the power can be redirected to the remaining vehicles and not left unused.

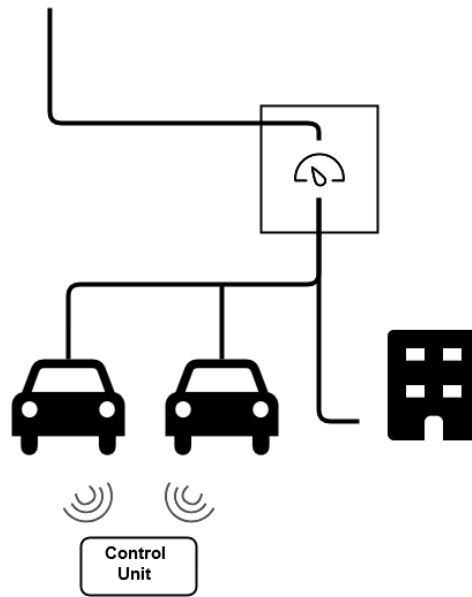


Figure 5 Layout of managed charging

The limit to the number of vehicles that can be charged is now controlled by the energy capacity available during the hours allocated for vehicle charging. This project focuses on charging during off-peak hours as the cost of electricity is cheaper and the building's electricity use is at its lowest leaving more power available. While the costs are greater and the inclusion of a third party to manage the system increases complexity this is the best option for maximising the number of vehicles that can be charged without upgrading the building's energy supply infrastructure.

In order to choose the type of electric vehicle charging system most suitable for an application, residents and Owners Corporations must identify their specific needs. With these goals in mind a decision on the type of charging system can be made. In line with the aims of this project it was necessary to cover both categories, this led to developing a model for each system.

3 METHODOLOGY

3.1 Research

During the research portion of the project no existing calculators were found that met the objectives. A number of online calculators were found, however these services focused on calculating the amount of money saved by replacing an internal combustion engine vehicle with an electric vehicle. These services required an individual to enter the cost of electricity at their home, the kilometres they travel and the model of the electric vehicle. With this information the calculator estimates the yearly cost owning an electric vehicle. While this is useful information for prospective electric vehicle owner, it was not relevant to this project.

It was found that the most significant cost to the Owners Corporation comes from the installation of the electric vehicle charging stations [5]. While the charging station itself is purchased by the electric vehicle owner, and in some cases free with the purchase of the vehicle, the Owners Corporation is at least partly responsible for the works and hardware necessary for installation. Works and hardware covers all necessary components, wiring, conduit and labour. These become a permanent part of the building and cannot be removed if the electric vehicle owner moves out of the building.

From looking at information on existing installations it was found that the cost of an electric vehicle charging system depends primarily on the distance between the meter panel and the location of the charging station. Installation of an electric vehicle charging system requires an electrician, and every extra metre the electricity needs to travel requires more wire, conduit and time. In high rise buildings the resident's car parks are most often underground and this may require concrete coring to pass the electricity between floors increasing the cost significantly [5]. Other factors found to affect cost of installation were the possible need for additional electricity meters, in some cases one per vehicle and permits for any necessary engineering works, further increasing the cost of installation.

While installation cost was found to be the largest hurdle for an owner corporation when implementing an electric vehicle charging system, there were other factors that need consideration. The next biggest concerns were the metering of electricity and how the electricity is paid for. The simplest solution involves the energy supplier installing an additional meter for every electric vehicle. In this method the new meter for charging is added to the vehicle owner's electricity bill and the owner is responsible for any maintenance to the charging port. This works well for one or two charging stations however for a larger number of stations a third party metering system is more appropriate. As described in the literature review, in this case the charging system is connected to the common power and each charging station is metered wirelessly. The EV owner pays a monthly subscription fee plus any for any electricity used. This is paid to a third party company that monitors usage and reimburses the Owners Corporation for the electricity consumed. In this model the company's monthly fee covers any ongoing maintenance costs. This setup is preferred where a large number of electric vehicle charging ports are required as there is less permanent hardware required and less of the installation cost is placed on the Owners Corporation. This system is also advantageous where space is a premium as no extra electricity meters need to be installed.

To direct the Owners corporations' choice on which charging system to implement, the power consumption of the charging system was a necessary consideration. When advising on the number of charging stations suitable for a building, the choice was made to keep the combined power consumption of the building and the charging system below the building's peak demand. Peak Demand is the maximum rate of power consumption over a given period. Peak demand charge can make up a significant part of the power bill and must remain as low as possible. Upgrading an electricity supply transformer is a large cost involving major work, interruption to the building's electricity supply and the cost would put it out of reach of most Owners Corporations. Staying under the buildings existing peak demand eliminates any need for upgrading the transformer.

3.2 Data collection

In order to meet the objectives of the project it was necessary to look at existing data relevant to the calculator's development. Important was the information on

- Specifications of vehicles to be charged
- Specifications of the Charging stations available
- Driving habits of owners
- Installation costs

3.2.1 Electric Vehicle Specifications

It was important to identify the types of EVs available in Australia as this has a large bearing on the type and capacity of the charging system and supporting electrical hardware. As can be seen in Table 1 the efficiency of electric vehicles varies from one to the next. The vehicle efficiency indicates the amount of energy used per kilometre and was important in finding the energy used each day. An average of 18kWh/100km was used for calculations in the electric vehicle charging models. Also the capacity of the each vehicle's batteries was found in order to ensure there was enough time to charge each vehicle. These statistics formed fundamentals when developing the models of the charging systems.

Manufacturer	Model	Electric Range (km)	Top Speed (km/h)	Electric Power (kw)	Battery (kWh)	Consumption (kWh/100km)	Price (AUD)
Tesla [9]	Model S 70D	375	230	285	70	18.67	\$70,000 USD
	Model S 90D	430	249	376	90	20.93	\$108,000 USD
Nissan [10]	Leaf	170	144	80	24	14.12	\$51,000
Ford [11]	Focus Electric	122	135	107	23	18.85	\$37,000
BMW [12][13]	i3	160	150	125	18.8	11.75	\$64,000
	i8	37	250	-	7	18.92	\$300,000
Mitsubishi [14][8]	MiEV	150	130	49	16	10.67	\$52,000
	Outlander PHEV	53	-	120	12	22.64	\$50,000
Volkswagen [15][16]	e-up	160	135	82	18.7	11.7	\$39,500
	e-Golf	145	-	115	24	12.7	\$37,500
Holden [17]	Volt	83	-	111	16.5	19.88	\$60,000

Table 1 Sample of Electric Vehicles in Australia

3.2.2 Electric Vehicle Charging Station Data

Along with vehicle information, charging stations come in many different configurations understanding the differences in charging rates affect the type chosen. Table 2 shows the different charging levels and their specifications. Level 1 is achievable from a conventional socket outlet and is sufficient for owners that only travel small distances. Level 2 is most commonly used residential charging setups, and for this project a 3.5 kW level 2 system was used as the typical case [REF jet charge]. Due to their high cost and power consumption level 3 chargers are almost exclusively used for destination charging a good example being Tesla's Superchargers.

Charging level type	Voltage level	Power level
Level 1	110-220 VAC	Up to 2 kW
Level 2	220 VAC	Up to 20 kW
Level 3, DC Fast Charge	420 VDC	50 – 150 kW

Table 2 Charger levels and specifications [7]

3.2.3 Driving Habits of Vehicle Owners

The driving habits of individuals were taken from the Survey of Motor Vehicle Use, Australia, 12 months ended 31 October 2014 [18]. There was considerable variation and as such adjustability was built into the model. This adjustability is also important when dealing with buildings that are further from major centres or residents that have a higher average daily travel distance. The average daily travel distance for private vehicles in capital cities was 30 kilometres [19], and this was used as a starting point for the electric vehicle charging models. It was chosen not to make provision for extended travel, such as weekend trips, at this stage. This was done due time constraints and to maintain the simplicity of the input information required.

3.2.4 Installation Costs

As identified as a major hurdle for the implementation of an electric vehicle charging system, installation costs for existing systems were hard to find. Anecdotal data for commercial installations Californian businesses were used as a guide for setting up the model [20], however this is not sufficiently accurate to be used at this time. As Wattblock's customers choose to implement electric vehicle charging systems in residential buildings empirical data will be collected and the model can be refined over time.

3.3 Product development

As Wattblock have different types of interactions with their clients it was necessary to develop four different tools. Each tool serves a different purpose; the first was basic model with minimal inputs and used averages and assumptions to produce outputs for a quick initial assessment. The second goes deeper into unmanaged charging systems with the ability to set parameters for individual vehicles and adds graphical outputs. The third model extends the second and covers managed charging systems where a central unit can control the charge rate of each vehicle charging station. The fourth tool consisted of a calculator to estimate installation costs involved in implementing an electric vehicle charging system. With these four tools Wattblock can give advice at each stage their interaction with a client.

3.3.1 Basic Model

The motivation behind the basic model was to create a tool that was quick and easy to use. To achieve this simplicity of use this tool only requires information from the client's electricity bill. The purpose of entering data from the electricity bill was to find the average electricity consumption during the cheaper off-peak period. From this information the tool provides a figure for the number of vehicles that can charge during off peak hours in an unmanaged or managed format.

As Wattblock's goal is to lower energy consumption and costs in their clients' buildings the decision to limit the electric vehicle charging to off-peak periods was financially motivated. The cost of electricity is significantly lower during the off-peak period. The decision to limit the power used when charging to the measured peak electricity consumption taken from the electricity bill was done for two reasons. The first reason was to eliminate the need to look at the cost of upgrading the electrical supply equipment to the building. The second reason was to simplify the input to the charging models. A professional assessment of the building's electrical supply equipment would be necessary for a more accurate maximum power level.

The first component of the basic model contains information about the electric vehicle or vehicles to be charged. From the research described earlier an average value was found for each of the vehicle's important parameters. Distance travelled was 30 km, vehicle efficiency was 18 kWh/100km and charging systems most commonly used 16A for charging [ref]. The vehicle parameters (Table 3) were setup with the ability to be modified for unique cases.

Enter billing data into white cells		
Parameter		Comments / Average values
Distance Travelled (km/day)	30	30
Car Efficiency (kWh/100km)	18	18
Charger current (A)	16	16
Charging efficiency (%)	90	
Charge rate (kW)	3.52	
kWh to full Charge	5.4	
Minimum charge time (hours)	1.53	
Off peak Start (PM)	11	10
Off peak End (AM)	7	6
Hours available to charge	8	
Billing start date	1/12/2016	DD/MM/YYYY
Billing end date	31/12/2016	DD/MM/YYYY
Total energy use (kWh)	7003.36	
Off peak energy used (kWh)	3313.02	
Peak Demand Limit (kW)	25.73	
Days in billing period	31	
Off peak days (weekends)	8	
Weekdays	23	
Off peak hours	376	
Peak hours	368	
Average Off peak (kW)	8.81	
Available for charging (kW)	16.92	
Charging capacity unmanaged	4	Based off available rate (kW)
Charging capacity managed	22	Based off available capacity (kWh)

Table 3 Basic Electric Vehicle Charging Model

The following equation used these parameters to calculate the maximum vehicle charging rate in kW to be used later in the process.

$$\text{Charge rate (kW)} = \frac{220V \times \text{Charger Current(A)}}{1000}$$

Next it was necessary to find the level of discharge of the vehicle's battery. This was found by multiplying the distance travelled by the vehicle's efficiency using the following formula. The efficiency was measured per hundred kilometres so it was also necessary to divide by one hundred.

$$\text{Capacity to charge (kWh)} = \frac{\text{Car efficiency} \left(\frac{\text{kWh}}{100\text{km}} \right) \times \text{Distance Traveled} \left(\frac{\text{km}}{\text{day}} \right)}{100}$$

After finding the level of discharge of the vehicles battery, the minimum time to reach full charge could now be found. The following formula shows how dividing the level of discharge by the maximum charge rate gives the charging time required.

$$\text{Minimum charge time (hours)} = \frac{\text{Capacity to charge (kWh)}}{\text{Charge rate (kW)}}$$

These calculations enabled the necessary data about the vehicles to be found. The next step was to accept information about the building's electricity consumption. This information came directly from the building's electrical bills. Data from one bill was sufficient, however yearly averages were able to provide better estimates. Then middle block of Table 3 shows the layout of this section.

The goal of the next component was to find two critical values, first the off peak time available each night. This is the most suitable time for charging and was found easily as the start and finish time of the off-peak energy is stated on the electrical bill. Finding the remaining value, the maximum charging rate available for the electric vehicle charging system, was more complex. To find the kilowatts available for charging during off peak hours it was necessary to find the number of off peak hours during the billing period. By subtracting the bill end date from the start date it was easy to find the number of days, however this was not enough. Weekends are considered off peak and need to be added to the total off peak hours during the billing period. Excel has a function for finding the number of weekdays between two dates and this was used to find the number of off peak days. The final formula for the number of off-peak hours was as follows:

$$\begin{aligned} \text{Total Off – peak hours} \\ = (\text{NETWORKDAYS}(\text{Start_date}, \text{end_date}) \times \text{Daily off – peak hours}) \\ + (\text{Total days} - \text{NETWORKDAYS}(\text{Start_date}, \text{end_date}) \times 24 \text{ hours}) \end{aligned}$$

With the total number of off peak hours found the next step was to find the average power used during these off peak hours. The following equation shows it was simply a matter of dividing the total off peak consumption, taken from the electricity bill, by the number of off peak hour during the same period.

$$\text{Average off peak power (kW)} = \frac{\text{total off peak energy consumption (kWh)}}{\text{Off peak hours (h)}}$$

Having calculated an average energy rate for the off peak hours, now it was possible to find the remaining power available for charging electric vehicles, this was done by subtracting the average off peak power from the peak demand for the billing period. With these two critical values it was now possible to find the maximum number of vehicle that can be charged with the available off peak energy.

Table 3 shows the final part of the basic model, the number of vehicles that can be charged was found using the following formulas:

$$\begin{aligned} \text{Charging capacity unmanaged} \\ = \frac{\text{Power for charging (kW)} \times \text{Charging efficiency (\%)}}{\text{Vehicle charge rate (kW)} \times 100} \end{aligned}$$

Charging Capacity Managed

$$= \frac{\text{Power for charging (kW)} \times \text{Hours(h)} \times \text{Charging efficiency (\%)}}{\text{Capacity to full charge (kWh)} \times 100}$$

To find the number of vehicles that can be charged in an unmanaged scenario the power available for charging was divided by the maximum vehicle charging rate. This was then multiplied by 0.9 to account for the efficiency of the charging hardware. Then the final result was rounded down to the nearest whole number. The result is one of the final outputs of the basic model.

For the managed charging scenario the maximum vehicle charging rate was not relevant. In this case the power available for charging was multiplied by the daily off-peak hours to find the total energy capacity available each day during the off-peak period. After finding the total daily off-peak energy capacity available this is then divided by the level of discharge in the vehicle's battery. Finally after accounting for the efficiency of the charging hardware and rounding down, the number of vehicles that can be charged under a managed charging system is found.

Excel was used to implement this process of calculating the number of electric vehicles that can be charged allows all the formulas and calculations to be completed behind the scenes. This created a simple process for evaluating the potential for electric vehicle charging in a client's building.

3.3.2 Unmanaged Charging Model

The second model developed builds on the basic model by adding the ability to enter parameters for each electric vehicle and average distance it travels each day. Furthermore this second model uses tables to simulate the charging of vehicles as time passes. This simulation allows the creation of a graphical representation of each vehicle's charging profile that can be used to support advice given in Wattblock's energy reports.

Comments	Parameters	Car 1	Car 2	Car 3
How far does the customer travel on an average day? (Average = 30)	Distance Travelled (km/day)	54	55	66
Vehicle Efficiency on Reference Sheet. (Average = 18)	Car Efficiency (kWh/100km)	14	19	15
Charger Current on Reference Sheet. (Most common = 16)	Charger current (A)	32	16	32
	Charge rate (kW)	7.04	3.52	7.04
	kWh to full Charge	7.56	10.45	9.90
	Minimum charge time (hours)	1.07	2.97	1.41

Table 4 Vehicle Inputs for the Unmanaged Charging Model

Table 4 shows a snippet the additional cells used to enter data for individual vehicles. Parameters for up to fifteen individual vehicles can be entered and information from the

electricity bill is entered in the same manner as the basic model. Finding the power and energy available for electric vehicle charging is calculated using the same technique as the basic model also. These numbers setup the basis for the simulating the charging profile.

Hour	Car 1 (kWh)	Car 2 (kWh)	Car 3 (kWh)
0	7.56	10.45	9.90
0.1	6.856	10.098	9.196
0.2	6.152	9.746	8.492
0.3	5.448	9.394	7.788
0.4	4.744	9.042	7.084
0.5	4.04	8.69	6.38
0.6	3.336	8.338	5.676
0.7	2.632	7.986	4.972
0.8	1.928	7.634	4.268
0.9	1.224	7.282	3.564
1	0.52	6.93	2.86
1.1	0	6.578	2.156
1.2	0	6.226	1.452
1.3	0	5.874	0.748
1.4	0	5.522	0.044
1.5	0	5.17	0
1.6	0	4.818	0
1.7	0	4.466	0
1.8	0	4.114	0
1.9	0	3.762	0
2	0	3.41	0

Table 5 Sample of Charge Required For Each Vehicle

Table 5 shows a small section of the table used to simulate the remaining energy required to charge each vehicle. As time passes the required charge decreases and reaches zero when the vehicle is fully charged. This table was automatically populated with a formula that draws from the previously calculated vehicle and charging information. In conjunction with the calculations an IF statement was used to prevent cells from returning negative values. The first cell was taken directly from the vehicle calculations, specifically the kilowatt-hours (kWh) to full charge. Then the second and subsequent cells use the following formula.

$$\begin{aligned} & \text{Remaining Charge Required (kWh)} \\ &= \text{Previous Cell} - (\text{Charge rate (kW)} \times 0.1\text{hours}) \end{aligned}$$

This completed the automatic population of the cells in Table 5 which represent the remaining energy required to charge each vehicle. In the example shown in Table 5 it can be seen that Car 1 and Car 3 which are charging at a high rate reach zero quickly, Car 2 on the other hand takes much longer to charge.

To complete the model another table was required to show the charging rates as time changes. This table is also populated automatically with a formula drawing from the data generated in Table 5. The first cell in Car 1's column in Table 6 is the difference between cell 1 and cell 2 of the previous table. Using this formula the rate of charge in kilowatts was found at each point in time.

Hour	Car 1 (kW)	Car 2 (kW)	Car 3 (kW)
0	7.04	3.52	7.04
0.1	7.04	3.52	7.04
0.2	7.04	3.52	7.04
0.3	7.04	3.52	7.04
0.4	7.04	3.52	7.04
0.5	7.04	3.52	7.04
0.6	7.04	3.52	7.04
0.7	7.04	3.52	7.04
0.8	7.04	3.52	7.04
0.9	7.04	3.52	7.04
1	5.2	3.52	7.04
1.1	0	3.52	7.04
1.2	0	3.52	7.04
1.3	0	3.52	7.04
1.4	0	3.52	0.44
1.5	0	3.52	0
1.6	0	3.52	0
1.7	0	3.52	0
1.8	0	3.52	0
1.9	0	3.52	0
2	0	3.52	0

Table 6 Sample of Charge Rate For Each Vehicle

With the charge rate over time now found the next step was to graph this data in a form that was easy to read and demonstrated how energy was consumed by vehicle charging. There were two relevant graphs for use in an energy report; Figure 6 shows the individual charge rates of each vehicle. This is useful for identifying heavy electricity users and gives a visual guide for the overall time taken to charge each vehicle.

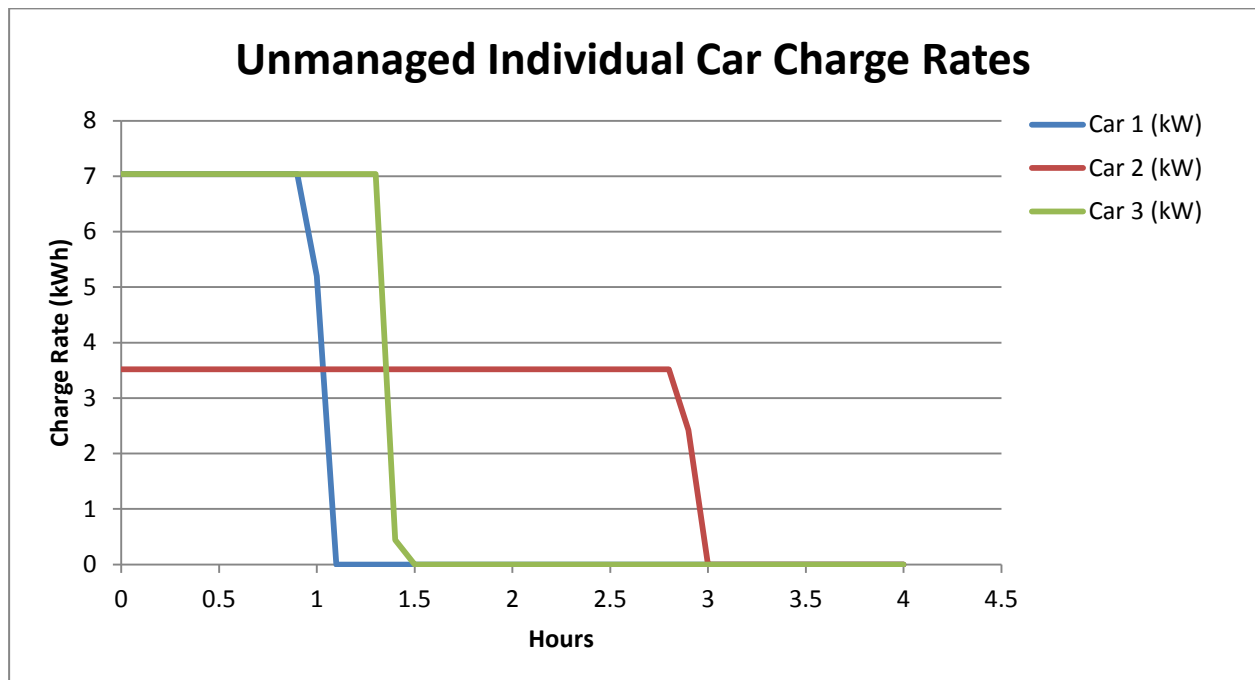


Figure 6 Individual charge rates from unmanaged charging model

Figure 7 shows the cumulative charge rates of each vehicle, each vehicles charge rate is stacked to show the total power drawn during charging. The probably the most useful in the energy report format as it displays a number of important details in an elegant format. This graph shows the peak charging rate, which is the most important of all the calculations as it is used to determine if the charging system is feasible. Alongside this the individual charging profiles of each vehicle are displayed and the total time for charging can be seen.

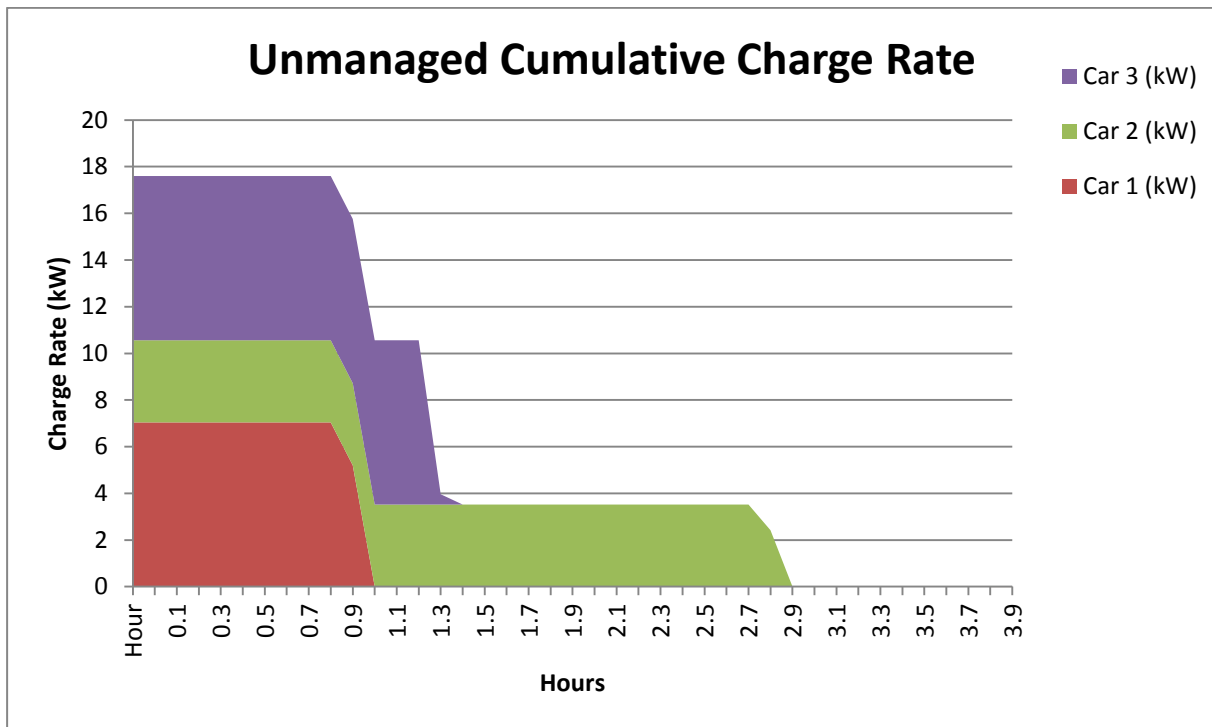


Figure 7 Cumulative charge rates from unmanaged charge model

With the addition of some extra vehicle information and automatically generated tables the unmanaged charging model was able to simulate the charging process of up to 15 electric vehicles. As described earlier in the literature review an unmanaged charging system is often most suitable for scenarios where a small number of vehicles require charging. With a number of Wattblock's clients approaching electric vehicle charging for the first time for only one or two vehicles this tool will be immediately useful.

3.3.3 Managed Charging Model

This tool takes the form of another model and was developed to simulate charging of multiple electric vehicles where the rate of charge is limited by a chosen limit or the building's electricity supply infrastructure. By using a smart charging system with a central control unit it is possible to limit the total power used by the charging system at any one time. This allows additional vehicles to be connected without exceeding the building's peak demand. By doing this the number of vehicles that can be charged without upgrading electrical supply infrastructure can be maximised.

The layout in Microsoft Excel for this model is visually the same as the unmanaged charging model. Entering parameters from the electricity bill and the vehicles to be charged was the also the same. Table 7 shows how the data was entered into the white cells and this data will be used to demonstrate how the model works.

Parameters	Car 1	Car 2	Car 3	Car 4
Distance Travelled (km/day)	54	55	66	45
Car Efficiency (kWh/100km)	14	19	15	18
Charger current (A)	60	16	32	32
Charge rate (kW)	13.2	3.52	7.04	7.04
kWh to full Charge	7.56	10.45	9.90	8.10
Minimum charge time (hours)	0.57	2.97	1.41	1.15
Off peak Start (PM)	11			
Off peak End (AM)	4			
Hours available to charge	5.00			
Billing start date	30/11/2016			
Billing end date	31/12/2016			
Total energy use (kWh)	7003.36			
Off peak energy used (kWh)	3313.02			
Peak Demand Limit (kW)	25.73			
Days in billing period	31			
Off peak days (weekends)	8			
Weekdays	23			
Off peak hours	307			
Peak hours	437			
Off peak Average (kW)	10.79			
Power for charging (kW)	14.94			
Energy for charging (kWh)	74.69			

Table 7 Test parameters for Managed Charging Model

Using the method outlined in 3.3.1 for the basic charging model, the power available for charging vehicles is found. In the example case used here it was 14.94 kW. The energy available for charging during the off- peak hours was found to be 74.69 kWh. This information was then used to model the charging of the four electric vehicles.

In order to simulate the charging of the electric vehicles, as before, automatically populated tables were necessary. In this model it was necessary to generate a table of charge rate in kilowatts of each vehicle first. This task was made more complex by having a limit to the available charge rate. The process began by finding the rate of charge for the first car, Car 1. If Car 1's maximum charge rate is less than the total power available, Car 1 will charge at its maximum rate and any remaining power is given to Car 2. The sum of charge rates for each car is always equal to or less than the 14.94 kW limit. At the same time the individual vehicle charge rates do not exceed the values calculated in Table 7.

Hour	Car 1 (kW)	Car 2 (kW)	Car 3 (kW)	Car 4 (kW)
0	13.20	1.74	0.00	0.00
0.1	13.20	1.74	0.00	0.00
0.2	13.20	1.74	0.00	0.00
0.3	13.20	1.74	0.00	0.00
0.4	13.20	1.74	0.00	0.00
0.5	13.20	1.74	0.00	0.00
0.6	0.00	3.52	7.04	4.38
0.7	0.00	3.52	7.04	4.38
0.8	0.00	3.52	7.04	4.38
0.9	0.00	3.52	7.04	4.38
1	0.00	3.52	7.04	4.38
1.1	0.00	3.52	7.04	4.38
1.2	0.00	3.52	7.04	4.38
1.3	0.00	3.52	7.04	4.38
1.4	0.00	3.52	7.04	4.38
1.5	0.00	3.52	7.04	4.38
1.6	0.00	3.52	7.04	4.38
1.7	0.00	3.52	7.04	4.38
1.8	0.00	3.52	7.04	4.38
1.9	0.00	3.52	7.04	4.38
2	0.00	3.52	7.04	4.38
2.1	0.00	3.52	0.00	7.04
2.2	0.00	3.52	0.00	7.04
2.3	0.00	3.52	0.00	7.04
2.4	0.00	3.52	0.00	0.00
2.5	0.00	3.52	0.00	0.00
2.6	0.00	3.52	0.00	0.00
2.7	0.00	3.52	0.00	0.00
2.8	0.00	3.52	0.00	0.00
2.9	0.00	3.52	0.00	0.00
3	0.00	3.52	0.00	0.00
3.1	0.00	3.52	0.00	0.00
3.2	0.00	3.52	0.00	0.00
3.3	0.00	0.00	0.00	0.00
3.4	0.00	0.00	0.00	0.00
3.5	0.00	0.00	0.00	0.00

Table 8 Charge rates for example model

Using the example case to demonstrate the operation, Table 6 shows at the beginning Car 1 receives 13.20 kW, this is the maximum charge rate for Car 1 calculated in Table 7. The remaining 1.74 kW is directed to Car 2 and Car 2 charges below its maximum rate. After 0.5 hours Car 1 is fully charged and Car 2 and Car 3 can now charge at their individual maximum rates with some power leftover. This leftover power is now directed to Car 4. This demonstrates the table was able model the operation of the charging system without exceeding the maximum power available.

After the first table (Table 8) was populated a second table to model the remaining capacity to be charged for each vehicle was generated. This table used the rate from Table 8 to calculate the drop in kilowatt-hours for every time increment. Table 9 shows the figures for the example case.

Hour	Car 1 (kWh)	Car 2 (kWh)	Car 3 (kWh)	Car 4 (kWh)
0	7.56	10.45	9.90	8.10
0.1	6.24	10.28	9.90	8.10
0.2	4.92	10.10	9.90	8.10
0.3	3.60	9.93	9.90	8.10
0.4	2.28	9.75	9.90	8.10
0.5	0.96	9.58	9.90	8.10
0.6	0.00	9.41	9.90	8.10
0.7	0.00	9.05	9.20	7.66
0.8	0.00	8.70	8.49	7.22
0.9	0.00	8.35	7.79	6.79
1	0.00	8.00	7.08	6.35
1.1	0.00	7.65	6.38	5.91
1.2	0.00	7.29	5.68	5.47
1.3	0.00	6.94	4.97	5.04
1.4	0.00	6.59	4.27	4.60
1.5	0.00	6.24	3.56	4.16
1.6	0.00	5.89	2.86	3.72
1.7	0.00	5.53	2.16	3.28
1.8	0.00	5.18	1.45	2.85
1.9	0.00	4.83	0.75	2.41
2	0.00	4.48	0.04	1.97
2.1	0.00	4.13	0.00	1.53
2.2	0.00	3.77	0.00	0.83
2.3	0.00	3.42	0.00	0.12
2.4	0.00	3.07	0.00	0.00
2.5	0.00	2.72	0.00	0.00
2.6	0.00	2.37	0.00	0.00
2.7	0.00	2.01	0.00	0.00
2.8	0.00	1.66	0.00	0.00
2.9	0.00	1.31	0.00	0.00
3	0.00	0.96	0.00	0.00
3.1	0.00	0.61	0.00	0.00
3.2	0.00	0.25	0.00	0.00
3.3	0.00	0.00	0.00	0.00
3.4	0.00	0.00	0.00	0.00
3.5	0.00	0.00	0.00	0.00

Table 9 Capacity remaining to full charge

Using this method for this table the data population for the managed charge model is complete. This data can now be displayed graphically in a number of formats for use in an energy report.

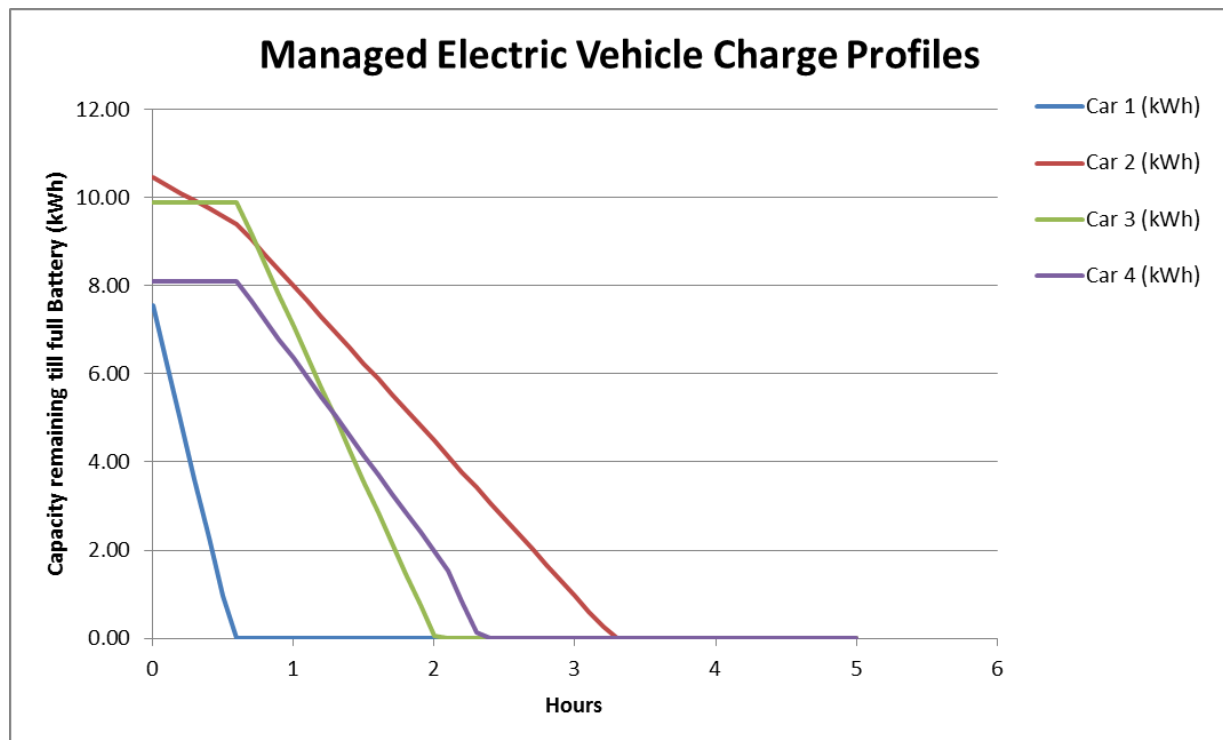


Figure 8 Example of charge remaining per vehicle

Figure 8 show the remaining charge required for each vehicle, this drops as time passes till it reaches zero and the vehicle's battery is full. This graph also shows the time taken to charge each vehicle when sharing electricity with other vehicles.

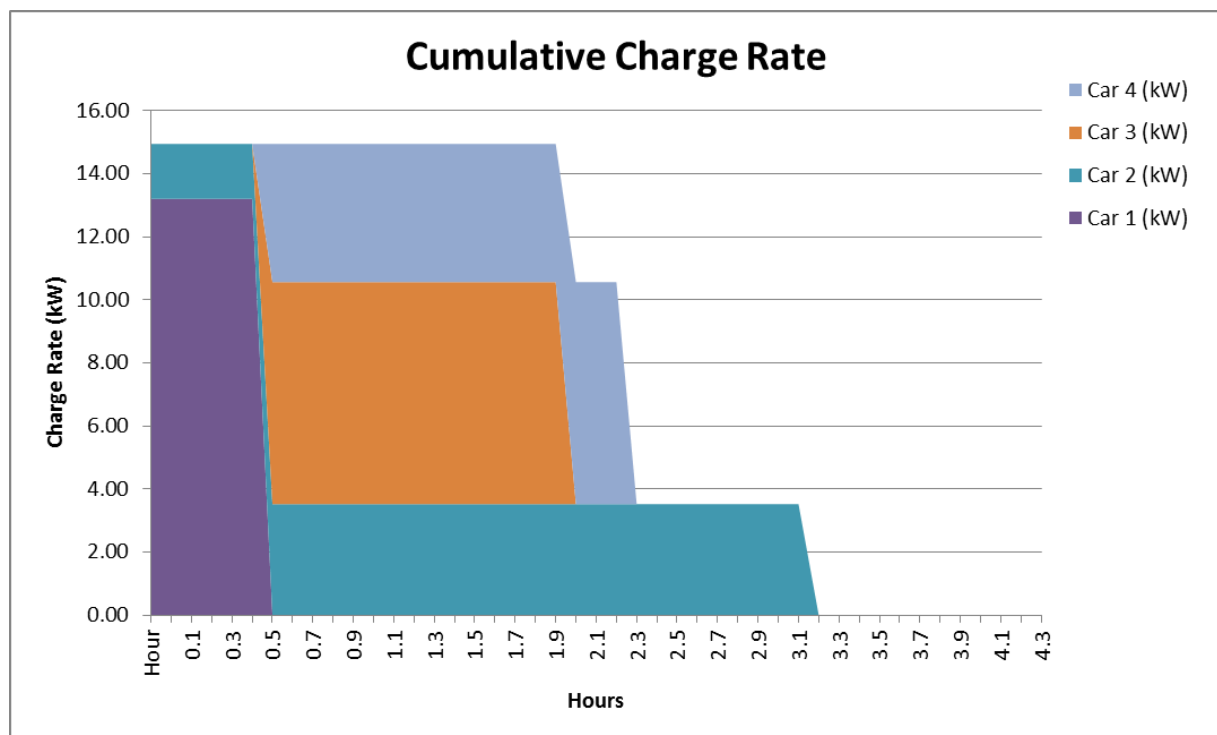


Figure 9 Total charge rate of electric vehicle charging system

To see the total amount of power being used at any time Figure 9 displays the cumulative charge rates of all the vehicles. As with the unmanaged charge model this graph shows the most relevant information and in an easy to understand format. This has the advantage of being able to show how the individual charge rates make up the total. The cumulative charge rate also demonstrates in a simple format the charging capacity not used. The white space under the charge rate limit of 14.94 is energy not used and means potential for more vehicles to charge. The individual car charge rates shown in Figure 10 is useful for showing how individual cars charge during the off-peak period

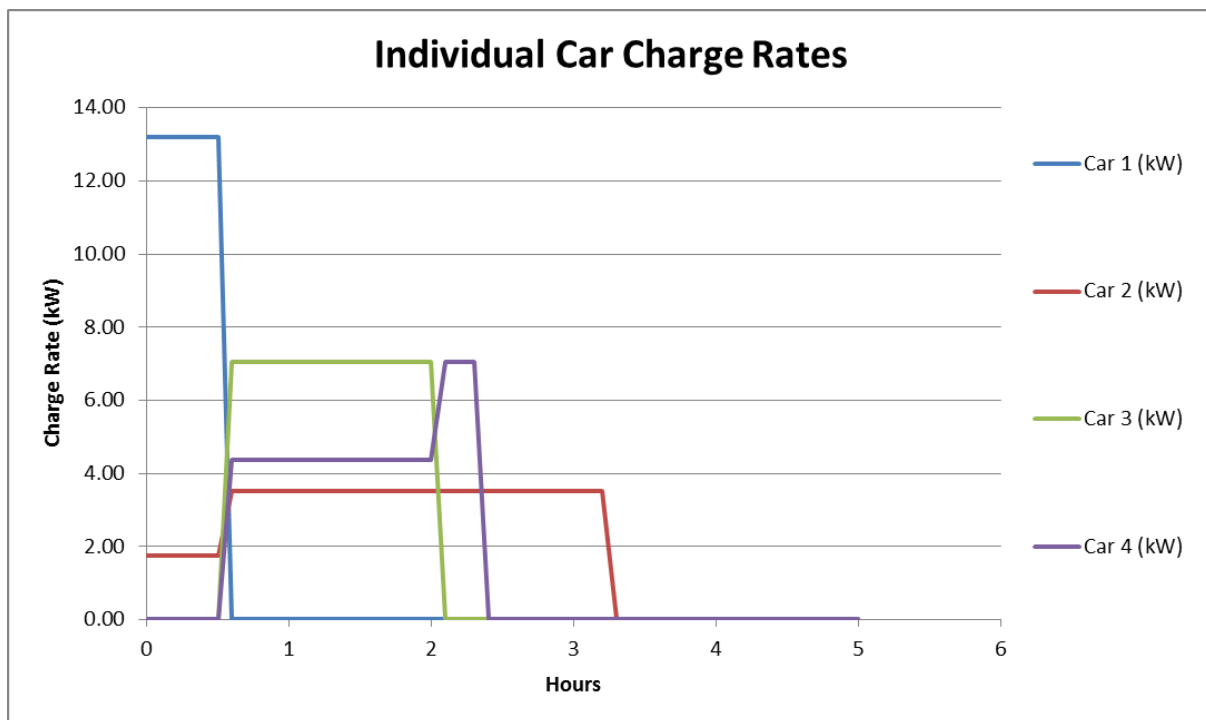


Figure 10 Example of individual charge rate

The total energy consumed is displayed in Figure 11, this shows a running tally of the energy consumed while charging electric vehicles over the off peak period. This graphical representation somewhat unnecessary as using final figure of the total energy used is just as effective. However it was included in the model as it was easy to implement

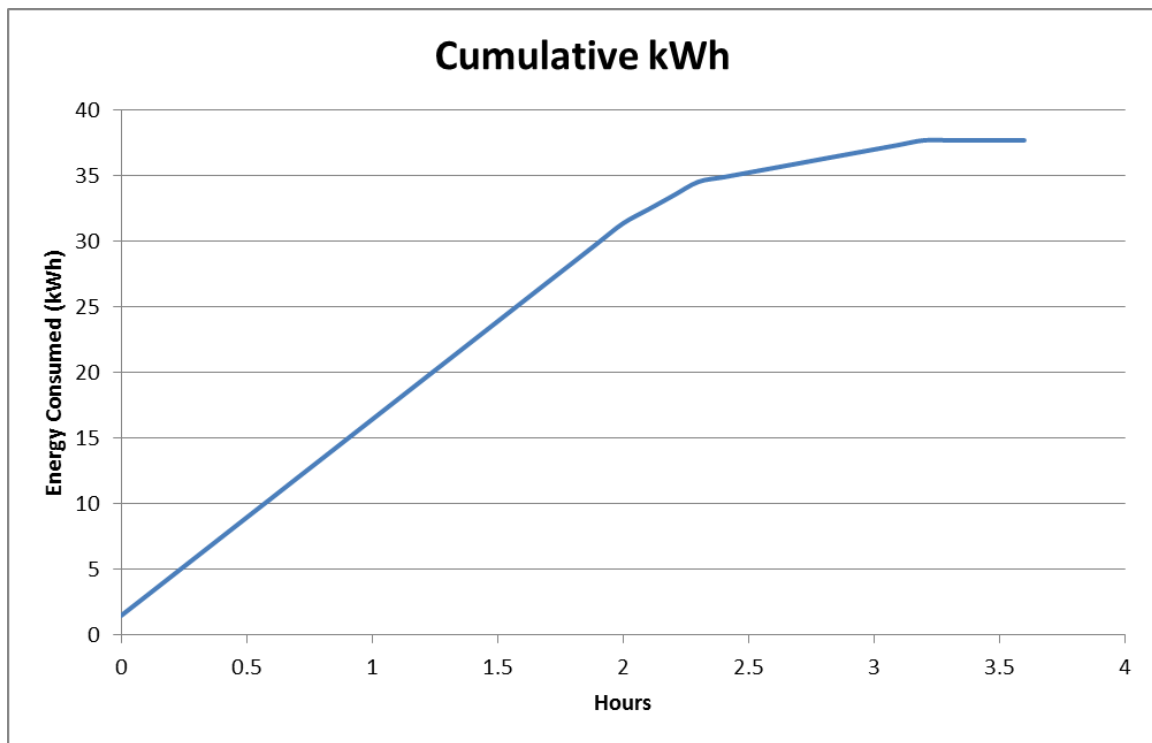


Figure 11 Example of total energy consumed over time

The four graphs shown here alongside the calculated figures form the output of the managed charging model are used to display the simulation in an easily readable format. From these graphical representations Wattblock is able to choose what is appropriate for use in their energy reports.

3.3.4 Installation Cost Calculator

The fourth and final part of the project took the form of a tool for estimating the installation cost of an electric vehicle charging system. By identifying features of a building that had a significant affect the cost of installing a charging system it was possible to prevent unnecessary data gathering and complexity. The goal of this tool was to use these significant building features to calculate the cost if installation. As no relevant existing data was found for the cost of installation in high rise buildings, the calculator was designed with future refinement in mind. Being adjustable Wattblock are able to enter their on data as they gather information when working with clients. The data from clients is averaged and used for calculation the total cost.

Factors affecting installation	
Base Install Cost (\$)	1200
Existing Conduit (1=yes, 0=no)	1
Distance to Meter box (m)	30
Number of floors between EVCS and Meter box	1
Additional meter required	1

Charger costs	
Unit cost	1265
Unit subscription costs	0
Maintenance (\$/year)	300

Installation cost per unit (\$)	3541.43
Cost per year (\$)	300

Source of cost	Avg	Case 1	Case 2
Base install cost (\$)	1200	1200	
Distance to meter box (m)	70	70	
Cost of conduit (\$)	3200	3200	
Per metre cost of conduit (\$/m)	45.71	45.71	
Cost of floors between EVCS and Meter box (\$)	1200	1200	
Cost of additional meters	70	70	
number of additional meters	1	1	
Maintenance (\$/year)	300	300	

Figure 12 Layout of the installation cost calculator

The layout of the installation calculator is shown in Figure 12, the first box holds the information gathered from the building, and the second is information about the electric vehicle charging hardware. Below the charger costs is the resulting installation cost and the yearly maintenance cost. In the final box is used for adding data from quotes or actual work done for clients. The average of this data is what is used when calculating the final figure.\

The total cost was found by summing the individual components. While some of these components were simply added together others, such as cost of conduit, depend on other factors, in this case the distance to the meter box.

At the stage of project completion the total installation cost was made up from the method shown below:

Base Install cost	<i>From case by case data</i>
+ Cost of conduit	<i>Distance to meter box × conduit cost per meter</i>
- Existing conduit	<i>Distance to meter box × 10</i>
+ Cost of floors	<i>Number of floors × cost per floor</i>
+ Cost of electrical meter	<i>From energy supplier</i>
<u>Total installation cost</u>	

At the time of writing this installation cost calculator was not accurate enough for use. Future case data will refine the accuracy and further testing can be carried out to assess its performance at a later date.

4 CASE STUDIES AND RESULTS

To demonstrate and assess the electric vehicle charging models three test cases were chosen. Three of Wattblock's previous clients were selected for their variation in size and parameters. As mentioned previously the installation cost calculator does not have sufficient historical data to be accurate and hence was not used in the following case studies.

4.1 Case study 1

4.1.1 Case Study Parameters

The first case study is consisted of a large client, both in number of units and energy use. This client's building consisted of 4 individual towers with a total of 371 units. Along with the residential units this building contained several commercial outlets on the ground floor. The common area electricity consumption was approximately 105,000 kWh per month and more than six months of energy use data were obtained. Just over 50% of the energy used was during the off-peak period.

To test the function of the vehicle charging models Table 10 was created for the test vehicle parameters. The size of the building chosen enabled 15 vehicles to be entered to test the full functionality of the model. The distance travelled for each vehicle was generated by using a random number between 10 and 80 as these distances cover over 90% of the trips taken by vehicle owners in Australia [19]. The car efficiency was a random number between 10 and 29 as this was the range identified when looking at the efficiency of electric vehicles available in Australia shown in Table 1.

Parameters	Car 1	Car 2	Car 3	Car 4	Car 5	Car 6	Car 7	Car 8	Car 9	Car 10	Car 11	Car 12	Car 13	Car 14	Car 15
Distance Travelled (km/day)	71	60	13	64	20	19	23	25	24	36	59	67	52	16	49
Car Efficiency (kWh/100km)	20	12	29	19	21	11	18	18	16	27	22	22	10	21	29
Charger current (A)	32	16	32	16	32	16	32	32	16	32	16	32	16	32	16
Charge rate (kW)	7.04	3.52	7.04	3.52	7.04	3.52	7.04	7.04	3.52	7.04	3.52	7.04	3.52	7.04	3.52
kWh to full Charge	14.20	7.20	3.77	12.16	4.20	2.09	4.14	4.50	3.84	9.72	12.98	14.74	5.20	3.36	14.21
Minimum charge time (hours)	2.02	2.05	0.54	3.45	0.60	0.59	0.59	0.64	1.09	1.38	3.69	2.09	1.48	0.48	4.04

Table 10 Test vehicle parameters

4.1.2 Case Study Results

A sample of the outputs for the three vehicle charging models for the first case study are shown here. The full results are shown in Appendix 1.

Parameter	
Days in billing period	275.00
Off peak days (weekends)	79.00
Weekdays	196
Off peak hours	3464
Peak hours	3136
Average Off peak (kW)	150.72
Available for charging (kW)	27.28
Charging capacity unmanaged	6
Charging capacity managed	36

Table 11 Basic model results for case study 1

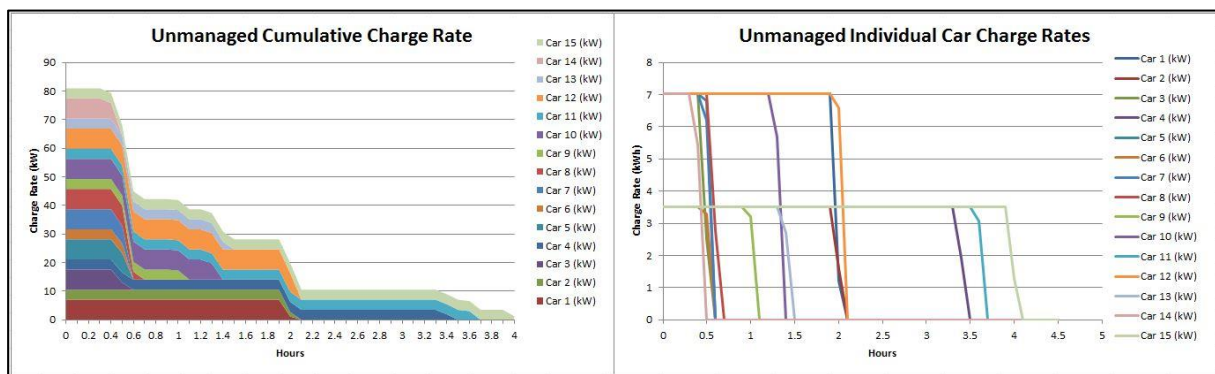


Figure 13 Unmanaged model results for case study 1

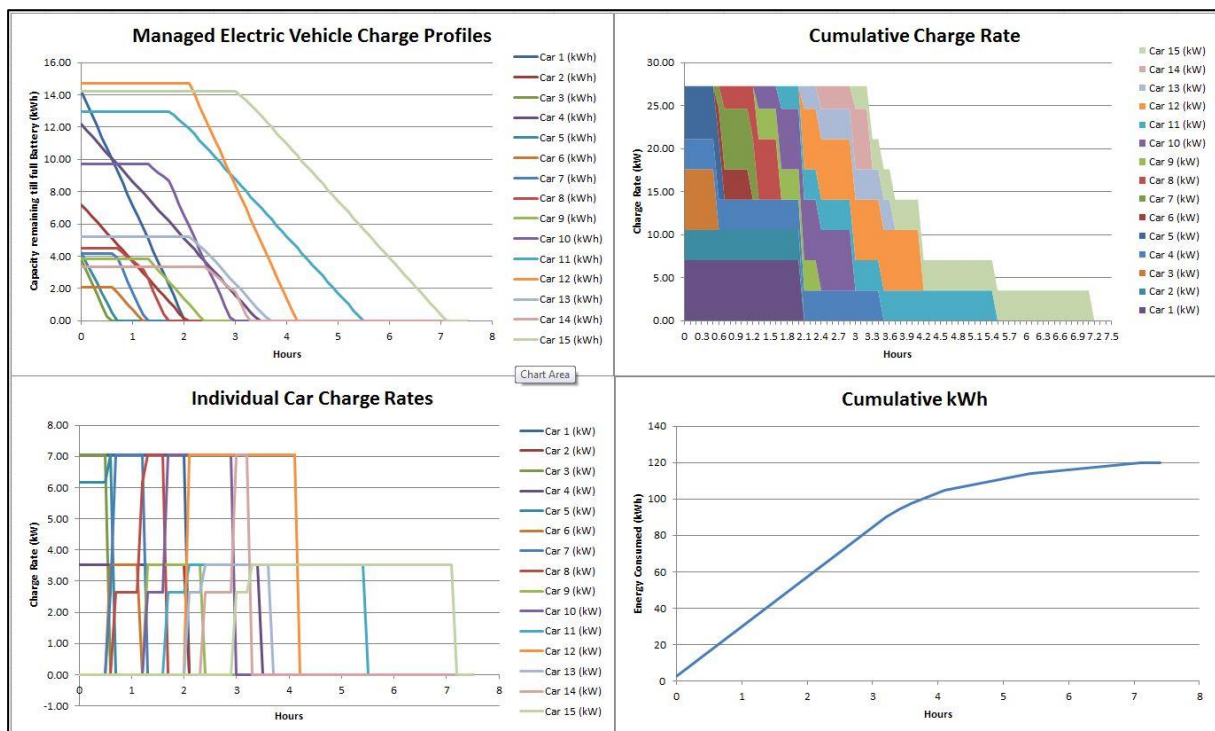


Figure 14 Managed model results for case study 1

4.1.3 Case Study Recommendations

Table 11 shows the building has the ability to charge six vehicles in an unmanaged charging system and 36 vehicles in a managed system. Entering the vehicle data into the Unmanaged Charging Model shows a peak energy use, shown by the cumulative charge rate in Figure 13, Figure 13 Unmanaged model results for case study 1 far higher than the permitted 27.28 kW found in Table 11. This is also indicated in the individual charge rates shown in Figure 13 with several vehicles charging at 7 kW the overall charging limit is quickly exceeded. This is to be expected as the basic model indicates only 6 vehicles are suitable to be charged in an unmanaged system and for charging any more a managed charging system would be recommended. In this case further complications arose from the fact that the common area electricity and the electricity used by the commercial outlets on the ground floor are both supplied by the same electricity meter. The cost of the electricity was broken up on a negotiated percentage basis. In the process of installing an electric vehicle charging system it may be necessary to install an additional electricity meter to distinguish the charging systems electricity use from that of the commercial and common areas. By completing an onsite assessment it was found that the underground parking area is a considerable distance from the electrical supply and installing individual meters and electrical wiring for each electric vehicle to be charged would be costly. This fact added weight to the case for a managed charging system.

The recommended solution would be to reallocate parking as mentioned in the steps identified in section 2.3 to position the parking spaces for charging near to the underground entrance. The entrance to the underground parking has a large automated garage door and this means there is existing electrical wiring to this location. Also by choosing the managed solution a third party company is responsible for monitoring and collecting money for the electricity consumption. This third party company will then reimburse the Owners Corporation for the electricity used. This eliminates the need to install multiple meters and running new electrical wiring for each charging station.

4.2 Case Study 2

4.2.1 Case Study Parameters

For the second case study a small building was chosen to test the functionality of the models across the range of potential buildings. The building chosen consisted of 27 units with a total of 4 floors. This building was chosen as it has a unique layout with the vehicle parking on the ground level in carports near the corresponding units. The electrical common area electrical consumption was modest at around 14,000 kWh per month with 7,700 kWh being used during the off-peak period. The peak demand was recorded as 30.97 kW.

Similar to Case Study 1 a sample of vehicles was made to test the unmanaged and managed charging models. For this case being a small building only 3 electric vehicles were modelled. The following values were again randomly generated:

Parameters	Car 1	Car 2	Car 3
Distance Travelled (km/day)	54	55	66
Car Efficiency (kWh/100km)	14	19	15
Charger current (A)	32	16	32
Charge rate (kW)	7.04	3.52	7.04
kWh to full Charge	7.56	10.45	9.90
Minimum charge time	1.07	2.97	1.41

Table 12 Electric vehicle test values for Case Study 2

4.2.2 Case Study Results

Displayed here is a sample of the results for each of the models and the full results can be seen in Appendix 1.

Days in billing period	31
Off peak days (weekends)	9
Weekdays	22
Off peak hours	392
Peak hours	352
Average Off peak (kW)	19.74
Available for charging (kW)	11.24
Charging capacity unmanaged	2
Charging capacity managed	14

Table 13 Basic model results for case study 2

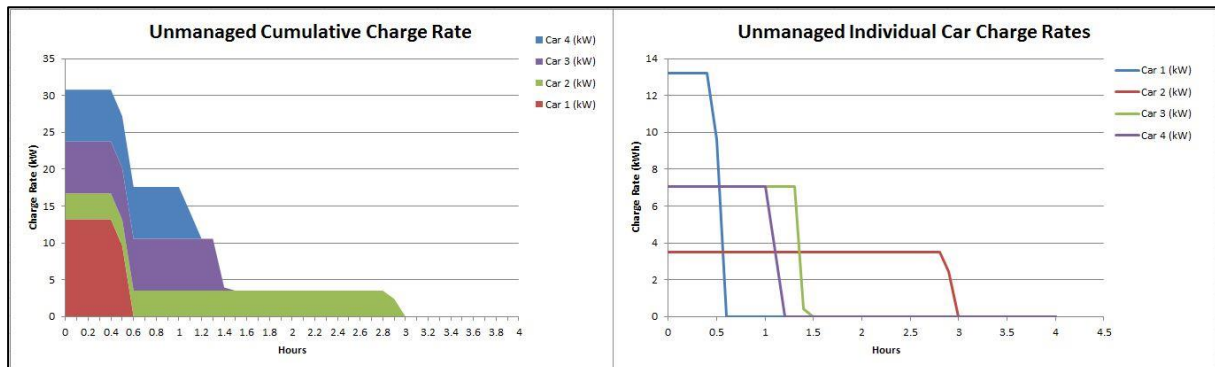


Figure 15 Case study 2 results for unmanaged model

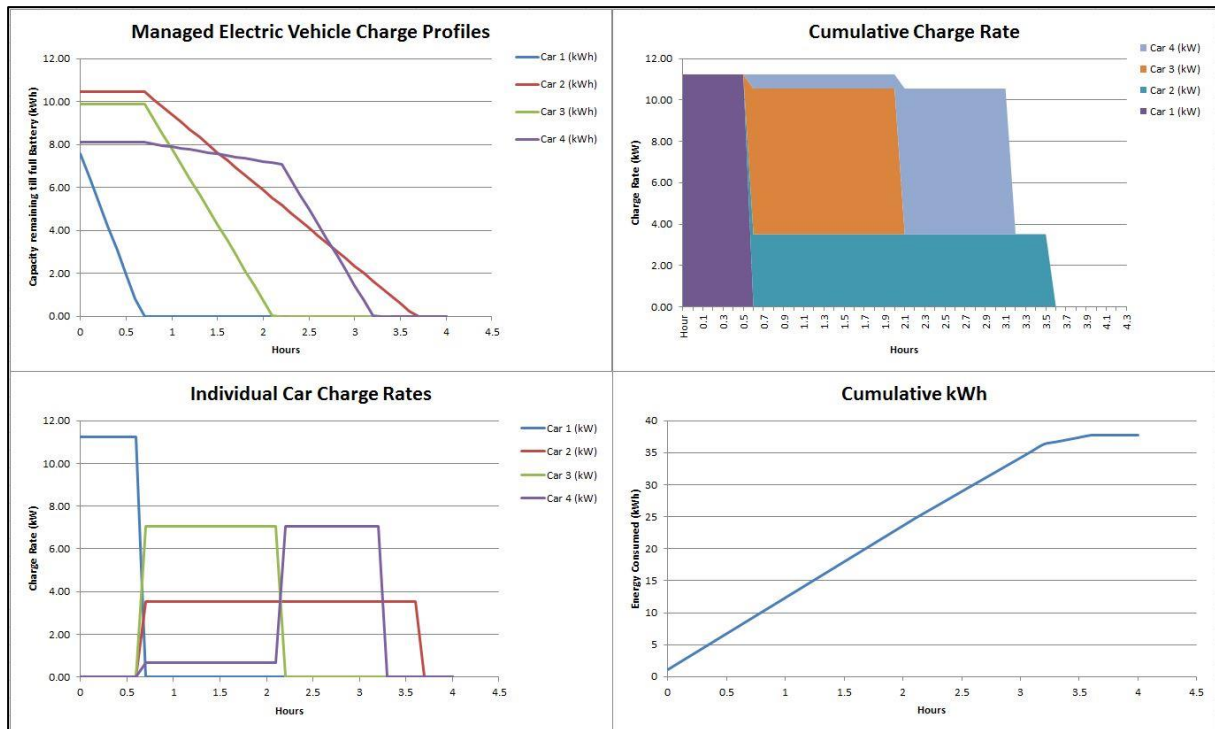


Figure 16 Case study 2 results for managed charging model

4.2.3 Case Study Recommendations

Table 13 shows the results from the basic charging model with a recommendation of 2 vehicles for an unmanaged setup and 14 vehicles in a managed charging setup. When the information was entered into the unmanaged charging model once again the peak power consumption is above the limit of 11.24 kW available for charging. By moving the vehicle parameters to the Managed Charging Model the charging profile can be seen in cumulative charge rate in Figure 16. This shows that four vehicles can be charged simultaneously without exceeding the 11.24 kW limit. The individual car charge rates show how the vehicles charge in a sequence with unused power passed to the next vehicle in the charging sequence. In this case the cumulative kWh climbs at a constant rate until around the 4 hour mark where all the vehicles have completed charging. With these four graphical representations in Figure 16 the process of charging the vehicles is easily displayed.

After completing an on-site assessment this site was found to be a unique case, as the vehicle parking was in close proximity to the apartment unit. In order to charge more than two vehicles the model shows a managed charging system is appropriate, however there is an alternative solution. The models developed here work on the basis of level 2 charging defined in section 2.5, in this situation level 1 charging from a conventional 220V external power outlet may be sufficient. Due to the proximity of the parking location the electricity source could be taken from the dwelling's fuse box with the addition of a dedicated circuit breaker. The prevention of unauthorized use can be achieved with the use of a lockable power outlet and the electricity consumption will be metered by the dwelling's existing electrical meter. A

drawback of this method of charging is the potential for a safety hazard similar to Figure 2, to avoid this situation the outlet must be placed in a location close to the charging vehicle.

The unmanaged charging model developed in this project is still useful here. The charging rate of each vehicle can be reset and entered as 10A, this is the maximum power available from a conventional power socket. By doing this the model will find the resulting charging times for each vehicle and generate a matching graphical representation.

4.3 Case Study 3

4.3.1 Parameters

For this third case study the building selected was typical of the buildings Wattblock regularly deal with. The building has 61 units on five floors with one level of underground parking. The electricity consumption was only slightly higher than case study 2, this is possibly due the energy saving measures already implemented by the Owners Corporation. The total energy consumption was 17,500 kWh with off-peak making up 8,100 kWh. The peak demand for this building was 44 kW.

The electric vehicle parameters used for the third case study were the same as that of case study two as in Table 12. The same parameters were used to enable a comparison between the outputs and enable the similarities and differences to be identified.

4.3.2 Results

A reduced sample of the electric vehicle charging models output are shown here, the full results are shown in Appendix 1.

Days in billing period	30
Off peak days (weekends)	8
Weekdays	22
Off peak hours	368
Peak hours	352
Average Off peak (kW)	22.05
Available for charging (kW)	22.11
Charging capacity unmanaged	5
Charging capacity managed	29

Table 14 Basic model results for Case Study 3

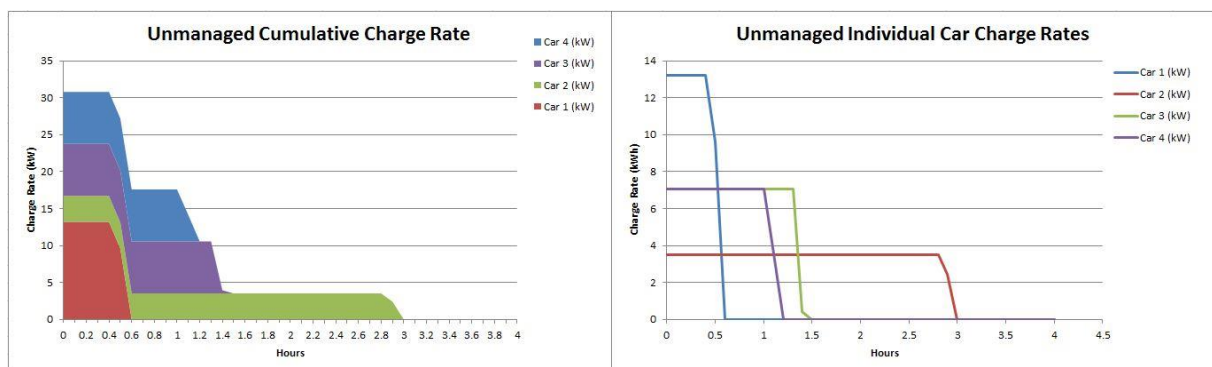


Figure 17 Unmanaged charging model results for case study 3

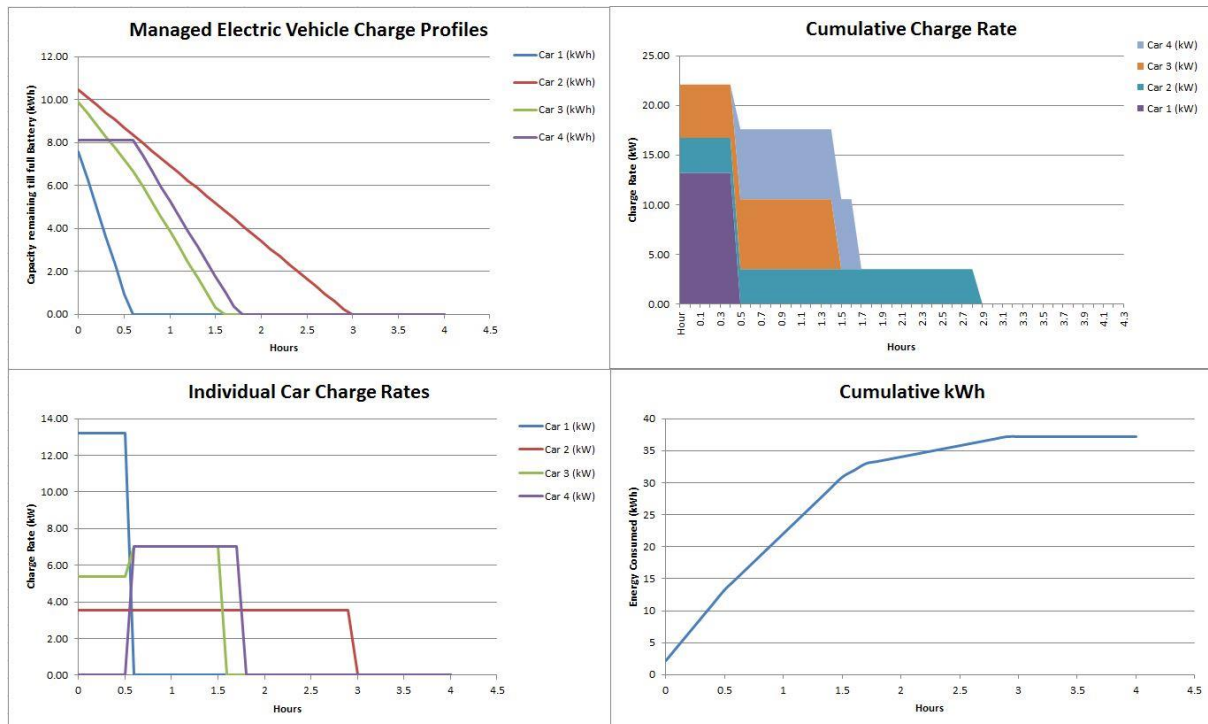


Figure 18 Managed charging results for case study 3

4.2.3 Case Study Recommendations

From the basic model results in Table 14 it was seen that the power available for charging was 22.11 kW this was in line with expectations and a little higher than the previous case study. Using the default average vehicle parameters the model shows 5 vehicles can be charged in an unmanaged scenario and 29 vehicles in the managed scenario.

When moving to the unmanaged charging model the graph of the cumulative charge rate in Figure 17 shows the total charge rate is over 30 kW and exceeds the limit of 22.11 kW, this is because the test parameters entered for the individual vehicles are significantly different from the average. This shows why it was seen as important to add the ability to adjust the vehicle parameters for the detailed models and makes the tools relevant in a wider range of cases. The individual car charge rates shown in Figure 17 show the culprit to be Car 1 with a peak charging rate of around 13 kW.

The results from the managed charging model show how the simulation is effective at maintaining the power used at or below the 22.11 kW limit. The cumulative charge rate in Figure 18 shows the charging at the maximum initially and drops after about half an hour. The reason for this drop was demonstrated in the electric vehicle charging profiles, Car 1 reaches full charge just after 0.5 hours. The individual car charge rates in Figure 18 show the operation of the managed charging model well. As Car 1 reaches full charge the charge rate in kW drops to zero and the power is moved to the remaining cars with Car 2 increasing to its maximum charging rate and Car 4 beginning to charge.

5 CONCLUSIONS

The aim of this project was to develop a tool to assist Wattblock when interacting with their clients. Two objectives were set out to achieve this aim. The first was to use Microsoft Excel to model electrical consumption when charging electric vehicles in high-rise buildings. The second objective was to develop a calculator for estimating the cost of implementing an electric vehicle charging system. In the end four tools were developed to achieve these objectives.

The first of the two objectives set out at the beginning of the project was fulfilled with the development three charging models. These consisted of a basic charging model, an unmanaged charging model and a managed charging model. These models applied engineering theory and research to Microsoft Excel to calculate power and capacity available for charging and then used tables to simulate the charging rates over time. With this data the models were then able to generate graphical representations for ease of reading.

The second objective was more difficult to achieve and the resulting installation cost calculator is complete but not useful at the time of completion of the project. During the research component of the project the major factors affecting the cost of installation were identified. However, without data to draw from, it was not possible to quantify how much each of these major factors affected the cost. To get around this the ability to include new installation cost data was added, by a breaking up the cost into its components and averaging the new data the accuracy of the cost estimation can be improved.

Using these tools in conjunction with Wattblock's existing procedure for an on-site assessment gave valuable insights into the advantages and disadvantages of different electric vehicle charging system. The case studies completed in the later part of the project demonstrate the tools' usefulness for assessing the energy consumption and potential for electric vehicle charging.

6 FUTURE DEVELOPMENT

As stated in the conclusion and shown in the case studies, in the current form the tools developed during the project are useful and have achieved the objectives that were set out at the beginning. Going forward from here Wattblock would gain a big advantage from working with an electrical company with experience installing electric vehicle charging systems to refine the tools. Some areas of the development and the resulting tools that can be improved are identified here.

6.1 Verifying Results

A shortcoming of the project process was the lack of measures put in place to test the validity of the results from the modelling tools. The formulas used for the calculations were all sound and based on engineering theory, however defining the parameters for finding the available power and energy available for charging were less theory based.

In an effort to simplify the operation of the models a restriction to charging at off-peak times was implemented. Also the measured peak electrical consumption from the electricity bills

was used as a limit for vehicle charging. The reasoning behind these choices was explained in section 3.3.1. Without real time energy use data it was not possible to know the actual energy during the off-peak period and the average was used in its place.

It is possible that the electricity consumption would fluctuate enough during the off-peak period that when combined with electric vehicle charging it may exceed the energy supply equipment's operating parameters. The responsibility of ensuring any plans to charge electric vehicles are safe ultimately fall with the installer, however Wattblock need to be aware of this when using the model to give advice.

A partnership with an electrical installation company would greatly benefit the future development of the electric vehicle charging models by giving the ability to assess the outcomes of the models

6.2 Types of Metering Systems

The project spent little time looking at electricity metering system used in high-rise buildings. Not much was known about the electrical hardware necessary upstream of the electric vehicle charging outlets. While the researched reports identified the major cost components during installation, the variation from building to building is expected to be significant especially in older buildings.

Bring an electrical company or expert on-board as a resource would give the ability to retrieve more detail from on-site assessments and identify different metering configurations. This information would be invaluable when giving advice on implementing charging systems and would also benefit Wattblock when looking at bulk metering for their clients.

Although not part of the models developed during the project, a better understanding of how the outputs will affect the building's existing electrical hardware would be an advantage when giving advice on electric vehicle charging.

6.3 Li-Ion Charging

In the development of the charging models a simplified process for charging Li-Ion batteries was used. When charging Li-Ion batteries the charging cycle is made up of two stages. During the first stage the battery is charged with a constant current, this is the method used in the project's charging models, this stage is used to charge the battery to approximately 80% capacity. After reaching 80%, the charging cycle moves to the second stage where the battery is charged with a constant voltage and the current gradually drops to zero and the battery is fully charged.

The charging models developed use the assumption the battery charges at a constant current until full. By making this assumption the process of modelling the battery charging process over time is greatly simplified. Using Microsoft Excel to implement the two stage charging cycle would be very difficult if not impossible. A better approach if this is to be developed further would be to move to a more suitable mathematical modelling program such as MATLAB

The use of the simplified charging cycle will not have ramifications on the electric vehicles in the current state. In the unmanaged charging model the cumulative charge rate would not be affected, only the charging time will be increased. There would not be a significant effect on the managed charging model either. As the charging vehicles move from constant current charging to constant voltage and the charging rate drops, the unused power would be diverted to the next vehicle in the sequence.

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8 APPENDIX 1

8.1 Outputs for Case study 1

8.1.1 Basic Model Results

Enter billing data into white cells		
Parameter		Comments / Average values
Distance Travelled (km/day)	30	30
Car Efficiency (kWh/100km)	18	18
Charger current (A)	16	16
Charging efficiency (%)	90	90
Charge rate (kW)	3.52	
kWh to full Charge	5.4	
Minimum charge time (hours)	1.53	

Off peak Start (PM)	10	10
Off peak End (AM)	6	6
Hours available to charge	8	

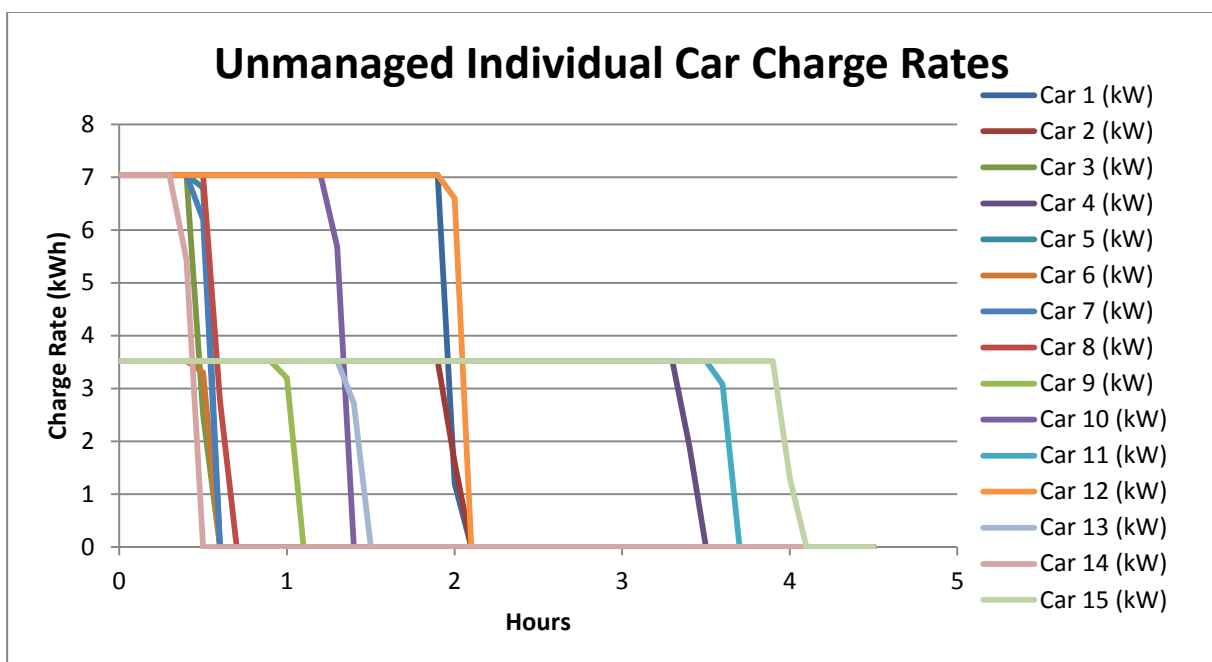
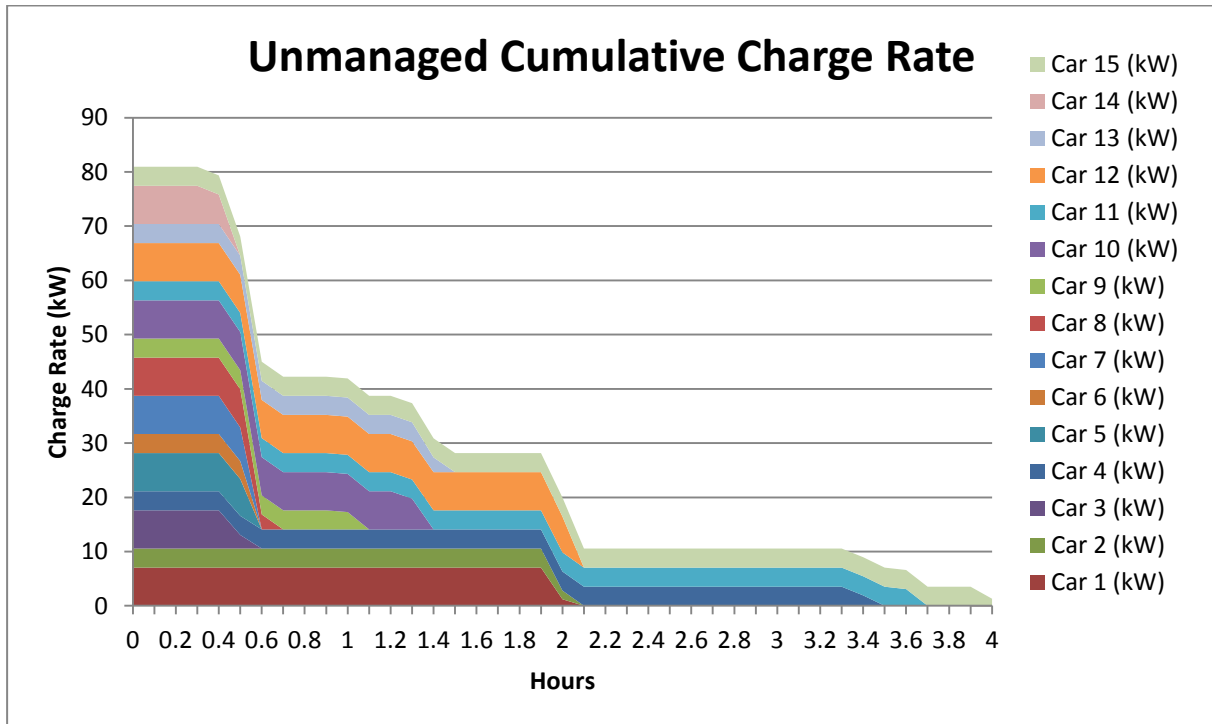
Billing start date	30/05/2015	DD/MM/YYYY
Billing end date	29/02/2016	DD/MM/YYYY
Total energy use (kWh)	1006209.9	
Off peak energy used (kWh)	522103.1	
Peak Demand Limit (kW)	178	

Days in billing period	275.00
Off peak days (weekends)	79.00
Weekdays	196
Off peak hours	3464
Peak hours	3136

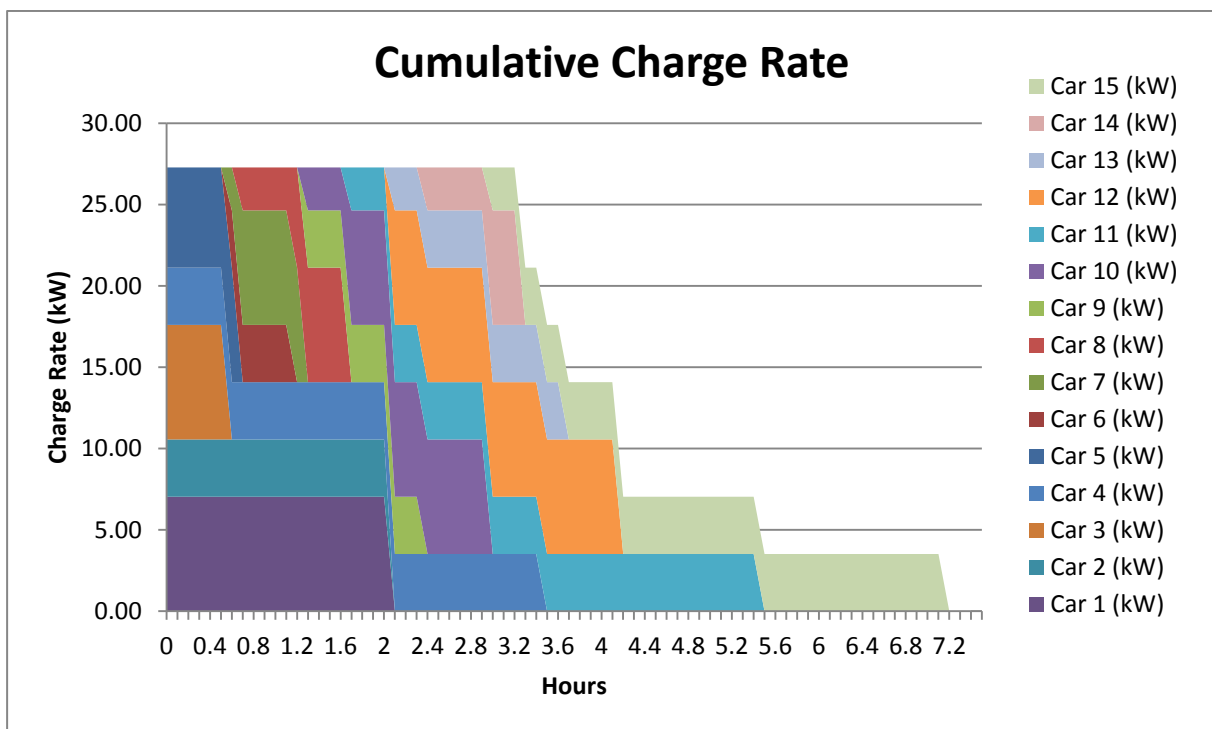
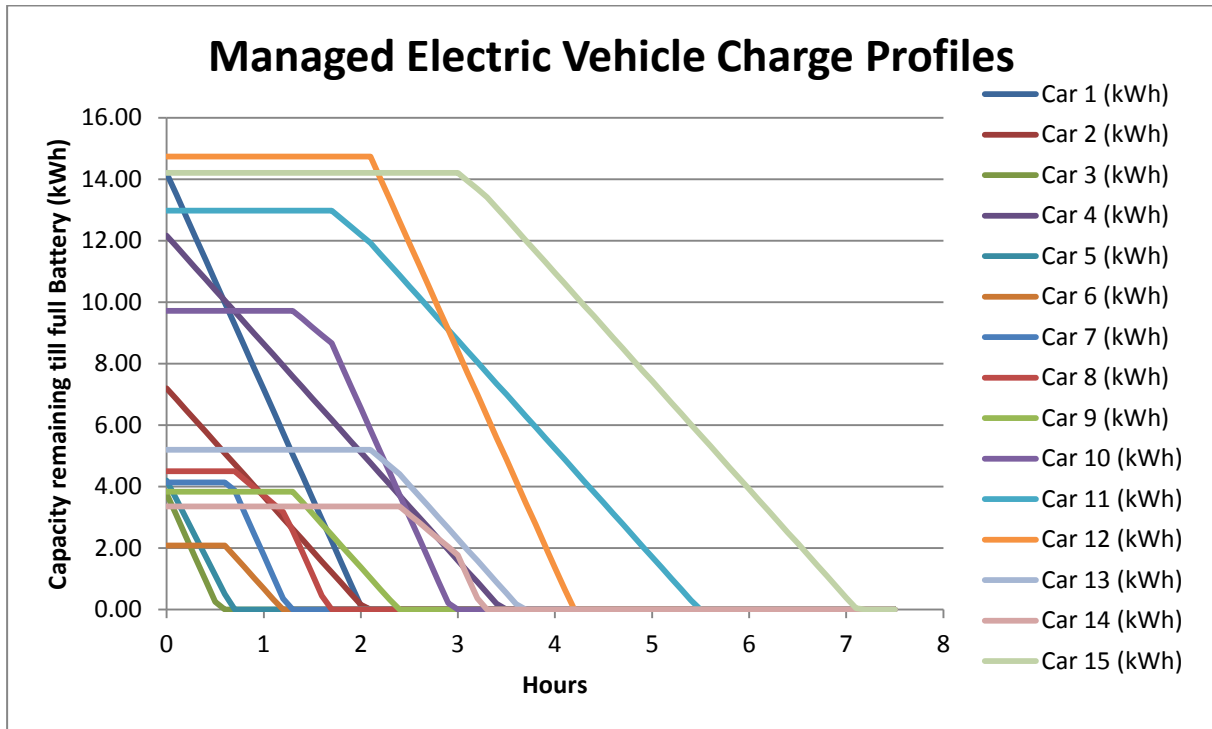
Average Off peak (kW)	150.72
Available for charging (kW)	27.28

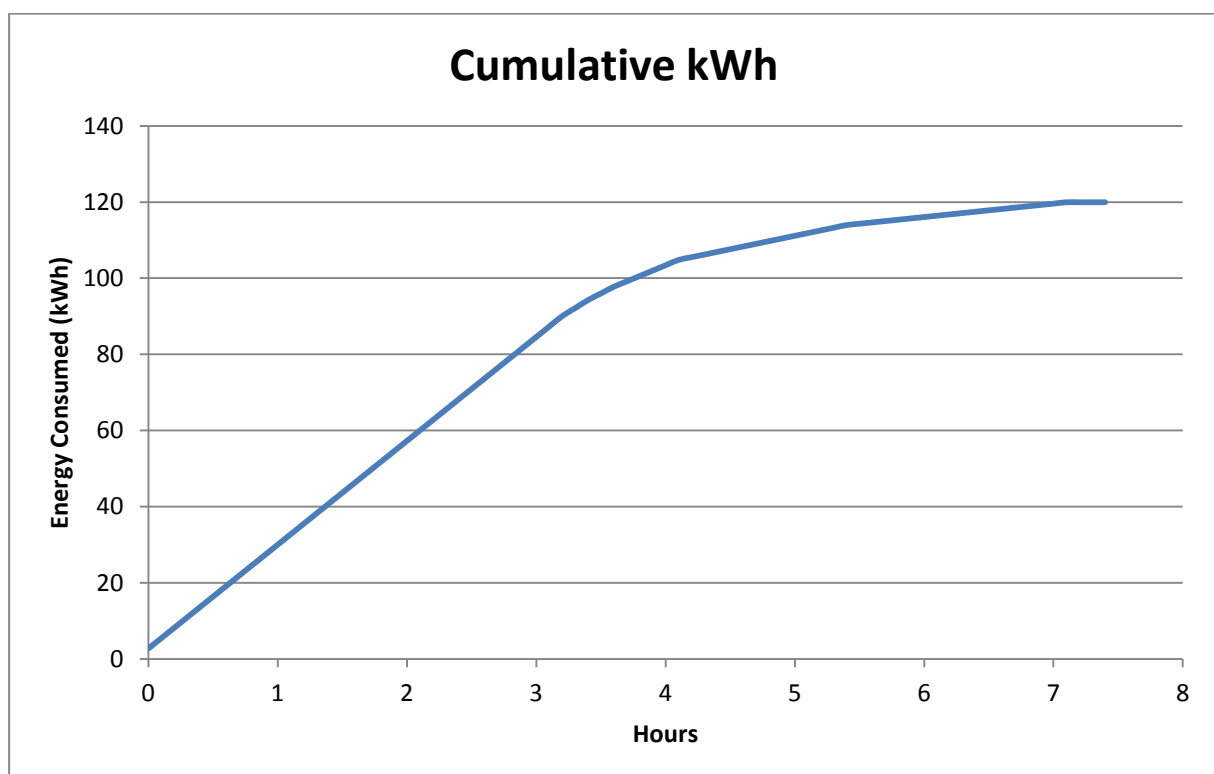
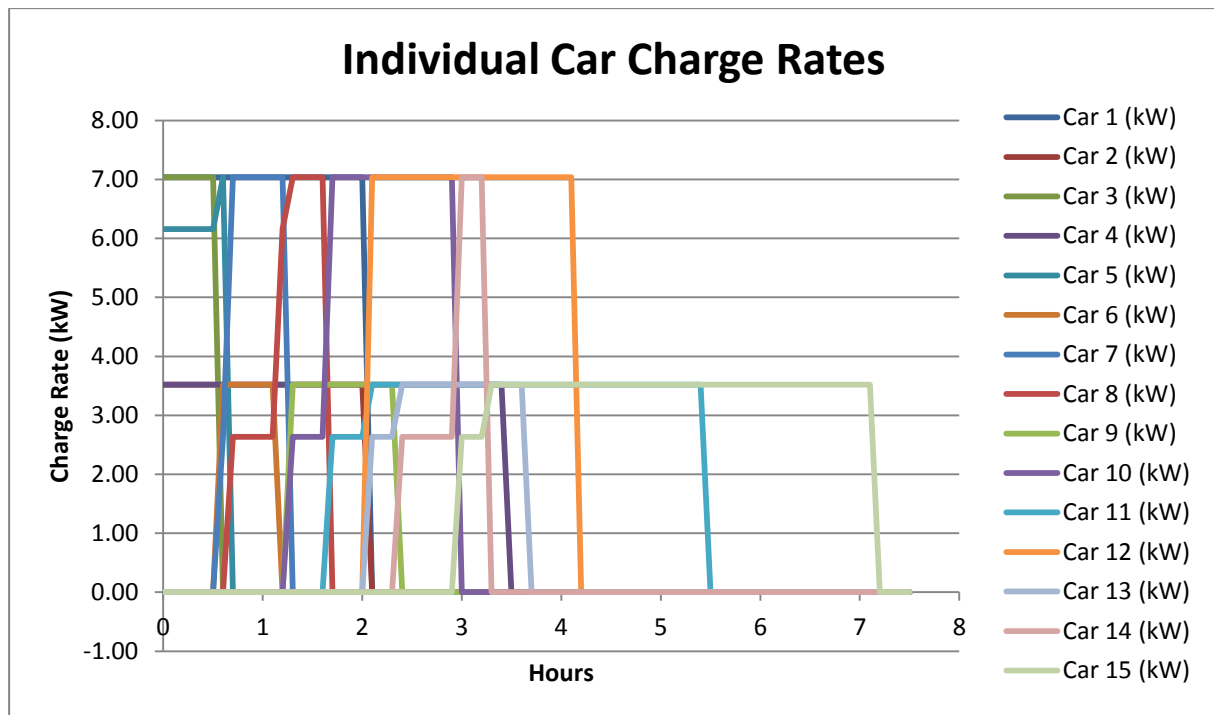
Charging capacity unmanaged	6	Based off available rate (kW)
Charging capacity managed	36	Based off available capacity (kWh)

8.1.2 Unmanaged Charging Model Results



8.1.3 Managed Charging Model Results





8.2 Outputs for Case Study 2

8.2.1 Basic Model Results

Parameter		Comments / Average values
Distance Travelled (km/day)	30	30
Car Efficiency (kWh/100km)	18	18
Charger current (A)	16	16
Charging efficiency (%)	90	90
Charge rate (kW)	3.52	
kWh to full Charge	5.4	
Minimum charge time (hours)	1.53	

Off peak Start (PM)	10	10
Off peak End (AM)	6	6
Hours available to charge	8	

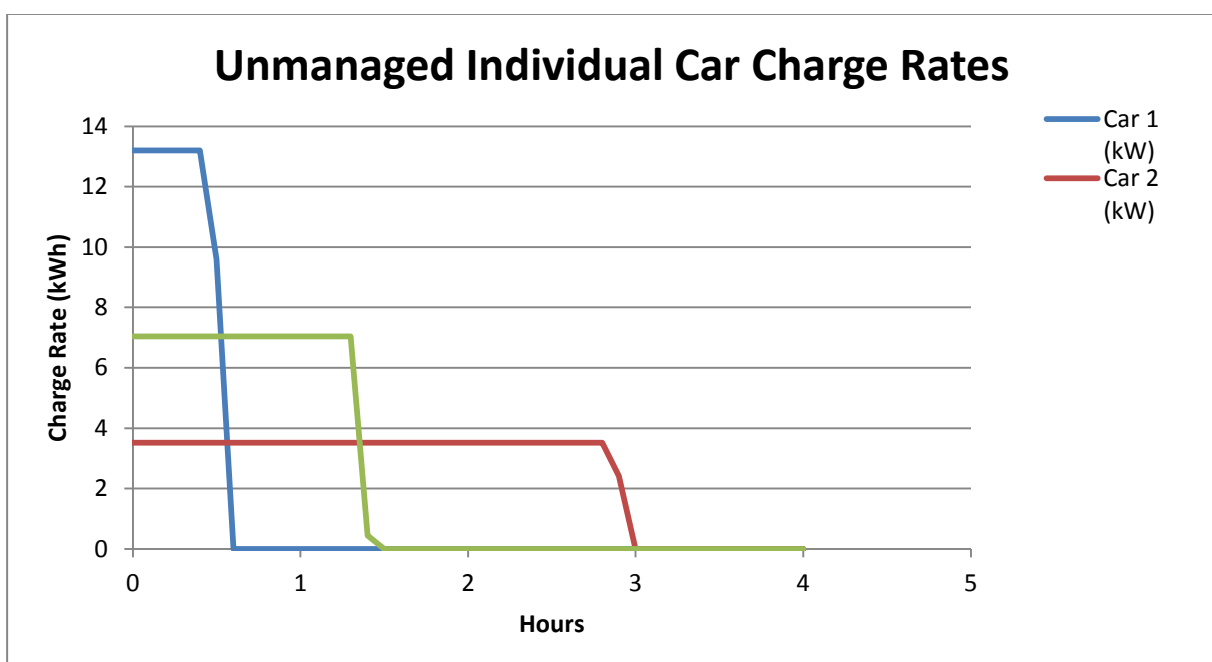
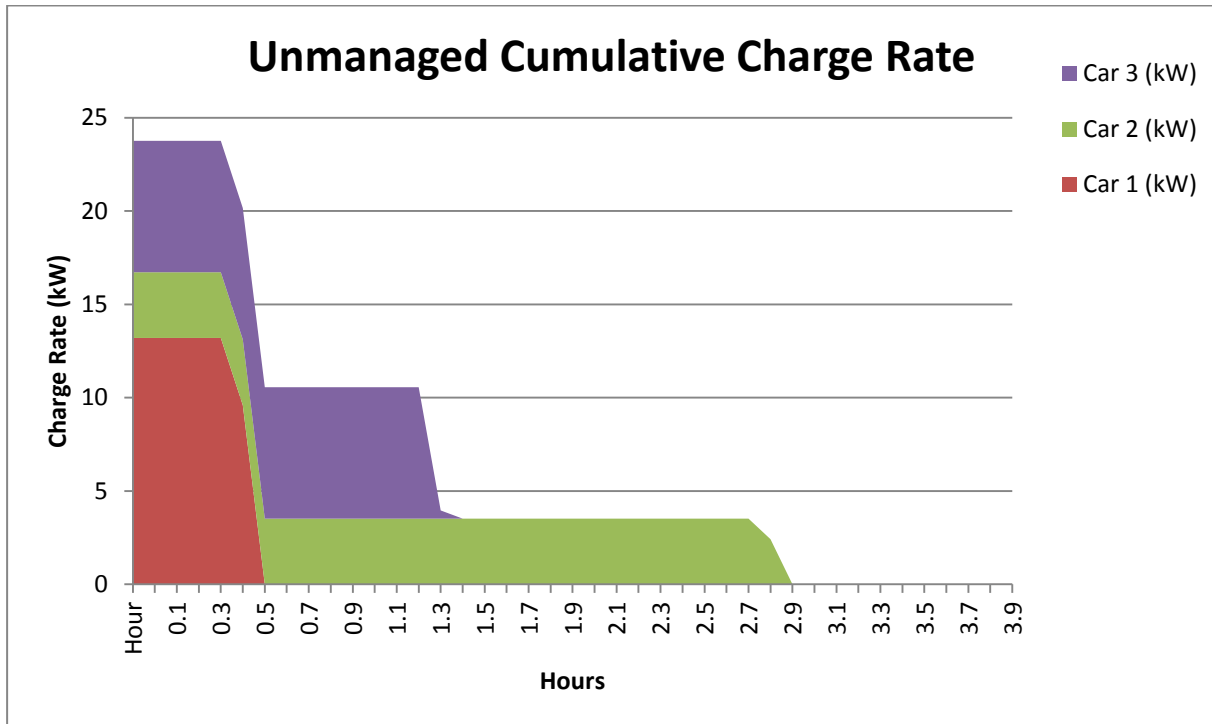
Billing start date	31/07/2015	DD/MM/YYYY
Billing end date	31/08/2015	DD/MM/YYYY
Total energy use (kWh)	14306.47	
Off peak energy used (kWh)	7736.67	
Peak Demand Limit (kW)	30.972	

Days in billing period	31
Off peak days (weekends)	9
Weekdays	22
Off peak hours	392
Peak hours	352

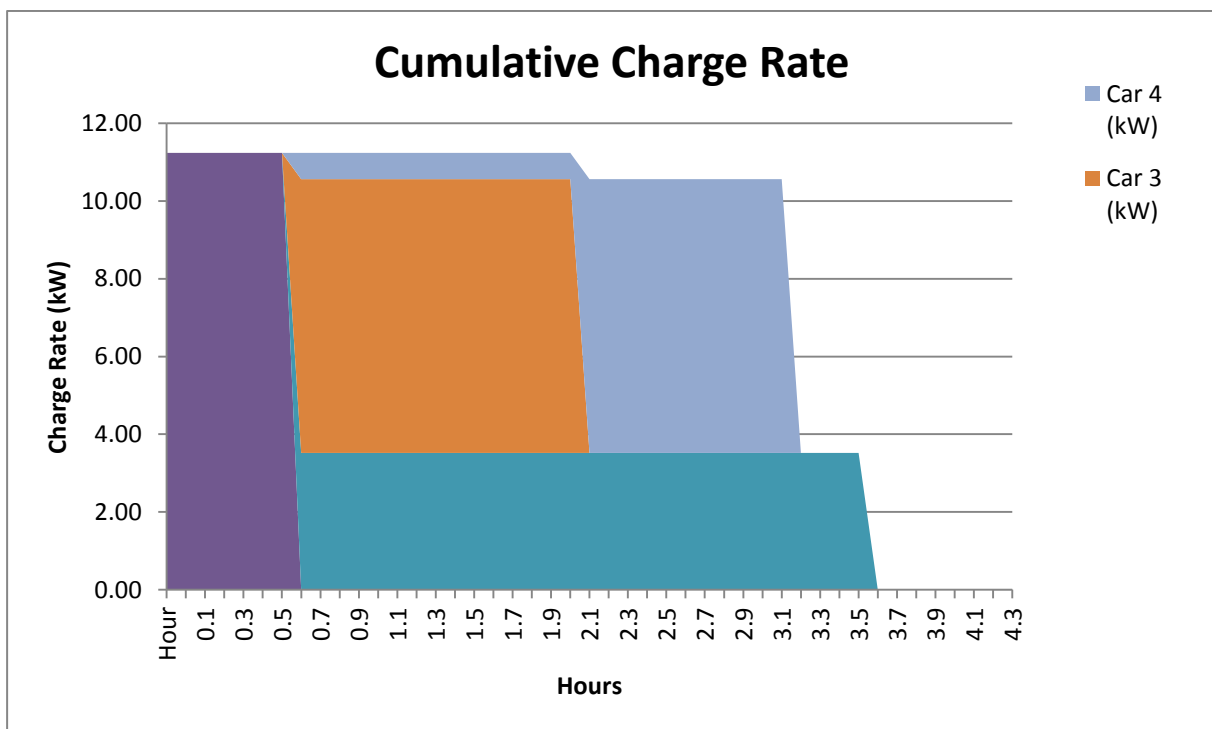
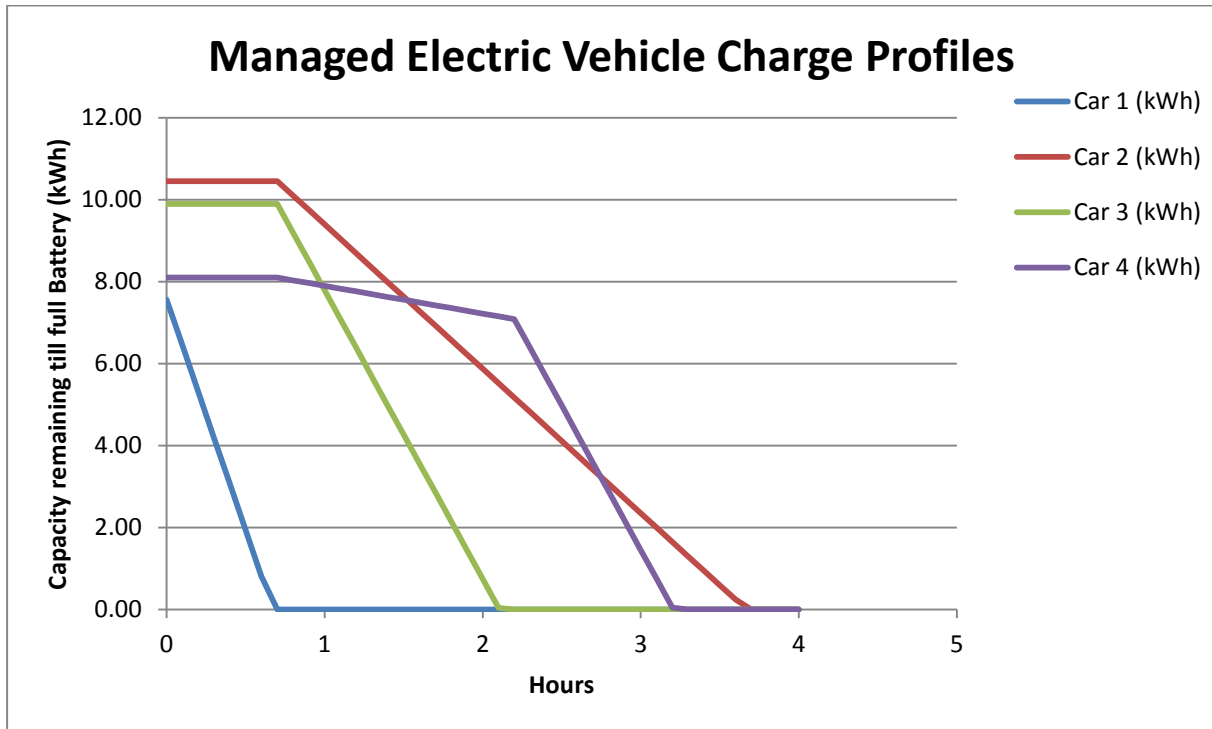
Average Off peak (kW)	19.74
Available for charging (kW)	11.24

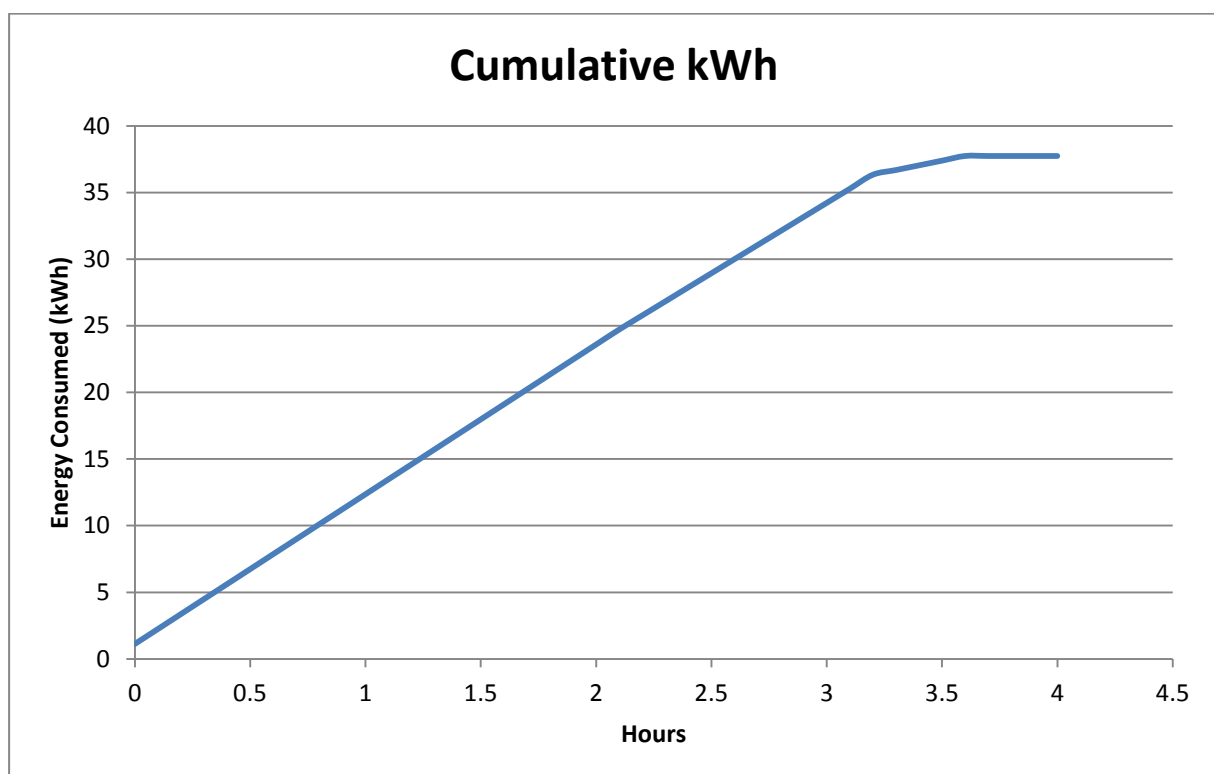
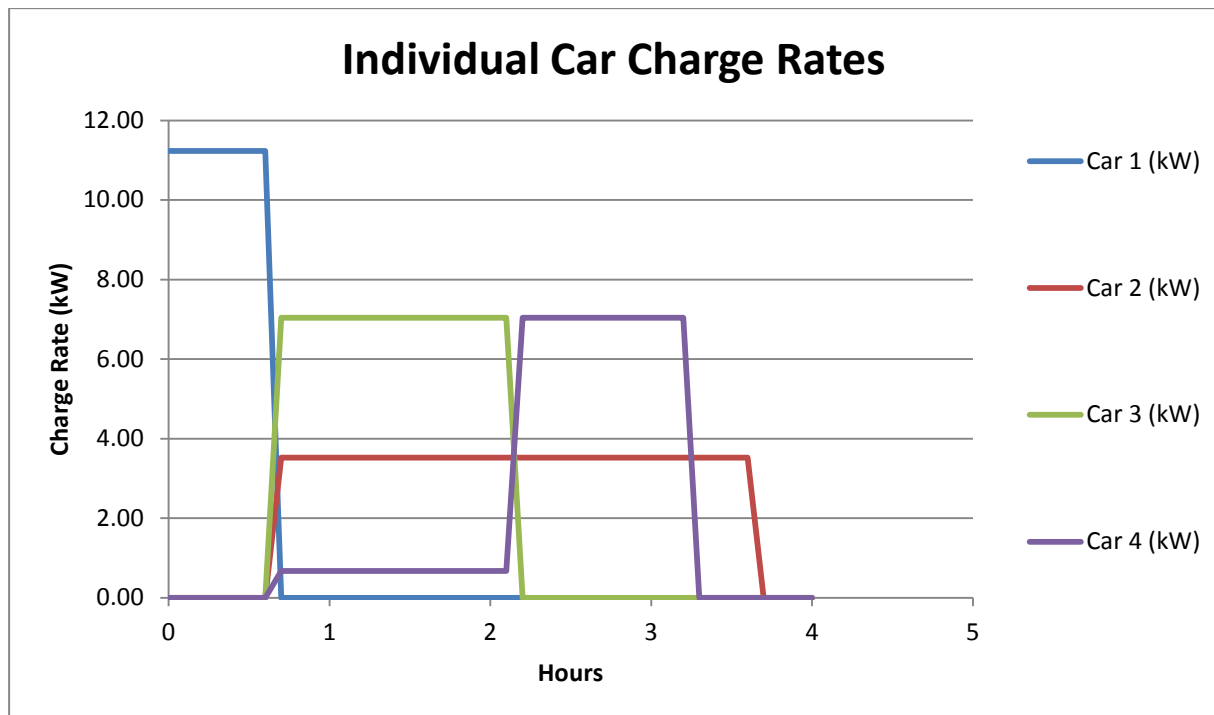
Charging capacity unmanaged	2	Based off available rate (kW)
Charging capacity managed	14	Based off available capacity (kWh)

8.2.2 Unmanaged Charging Results



8.2.3 Managed Charging Results





8.3 Outputs for Case Study 3

8.3.1 Basic Charging Model Results

Enter billing data into white cells		
Parameter		Comments / Average values
Distance Travelled (km/day)	30	30
Car Efficiency (kWh/100km)	18	18
Charger current (A)	16	16
Charging efficiency (%)	90	90
Charge rate (kW)	3.52	
kWh to full Charge	5.4	
Minimum charge time (hours)	1.53	

Off peak Start (PM)	10	10
Off peak End (AM)	6	6
Hours available to charge	8	

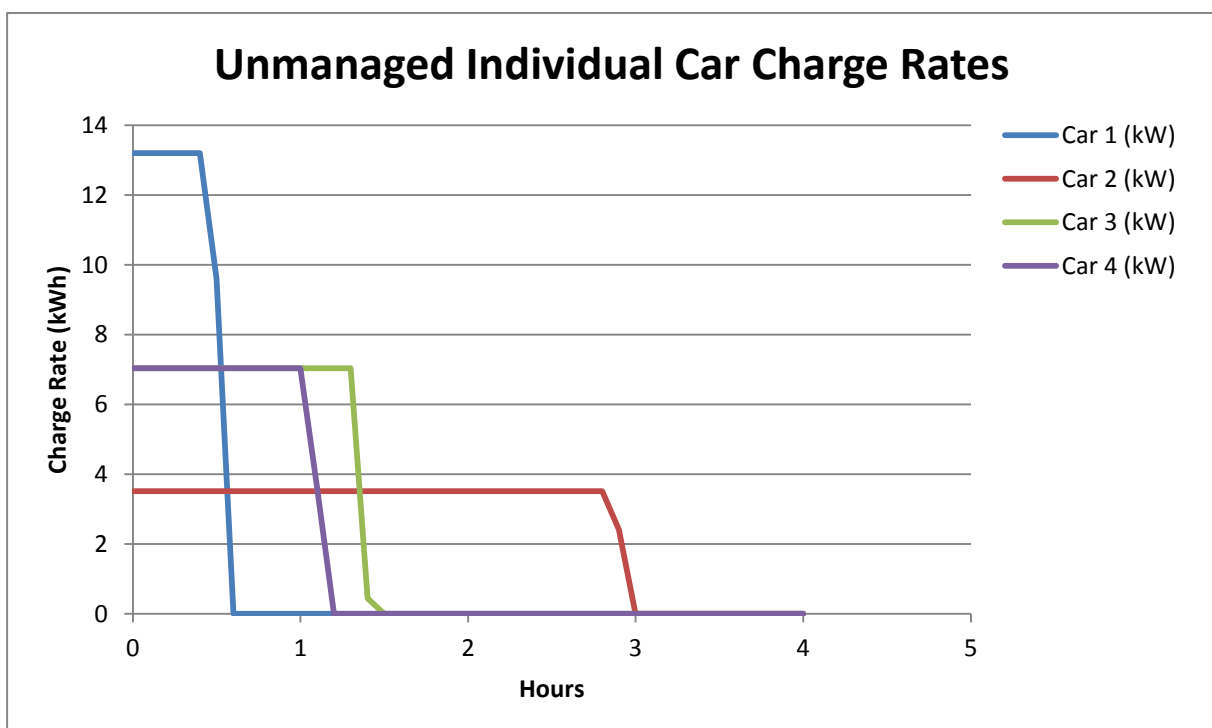
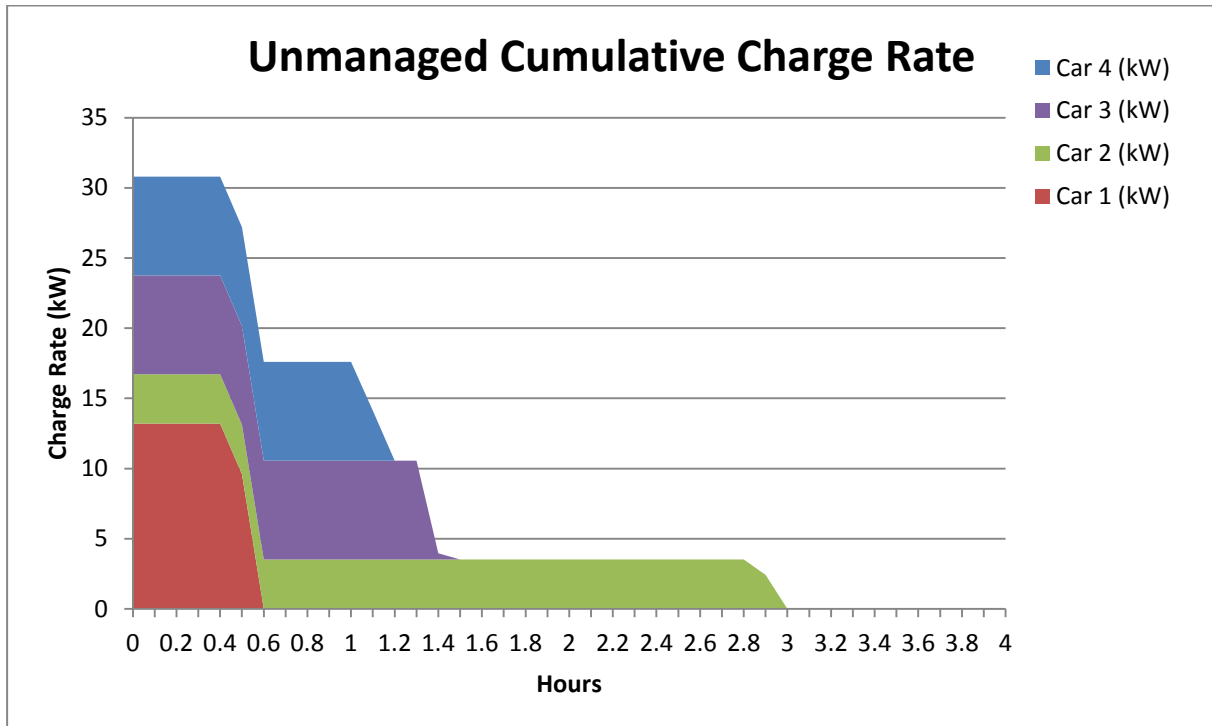
Billing start date	1/09/2015	DD/MM/YYYY
Billing end date	30/09/2015	DD/MM/YYYY
Total energy use (kWh)	17502.9	
Off peak energy used (kWh)	8113.95	
Peak Demand Limit (kW)	44.16	

Days in billing period	30
Off peak days (weekends)	8
Weekdays	22
Off peak hours	368
Peak hours	352

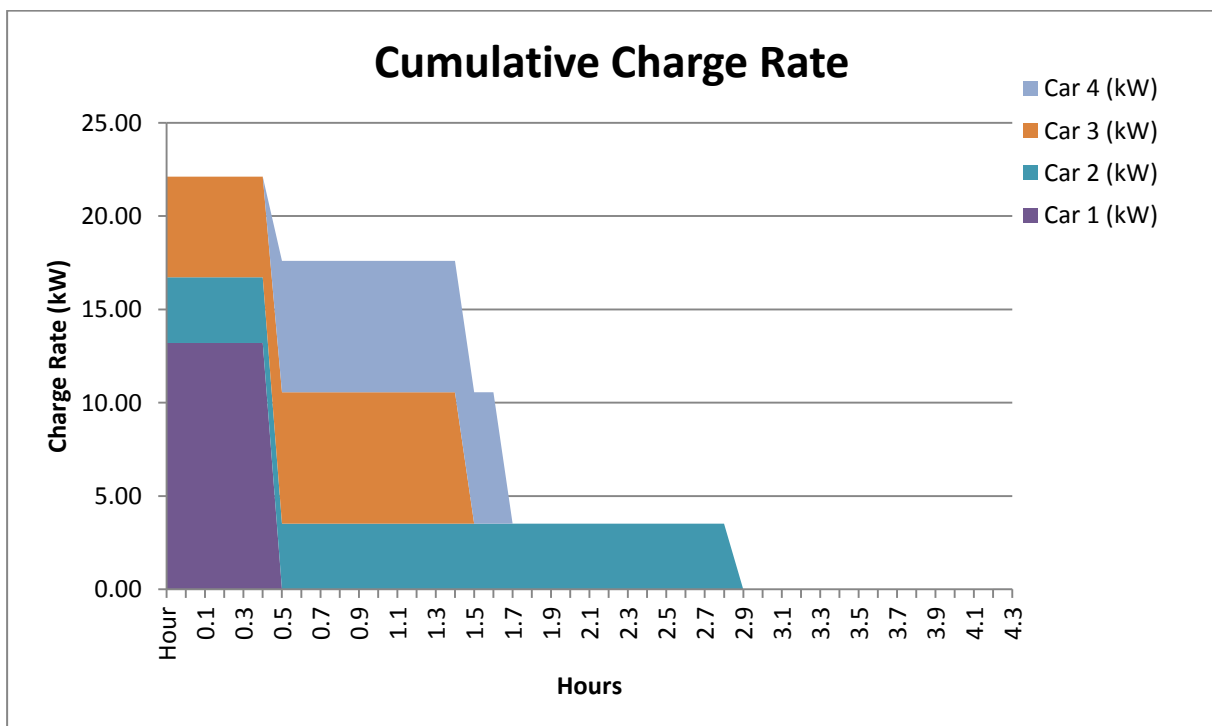
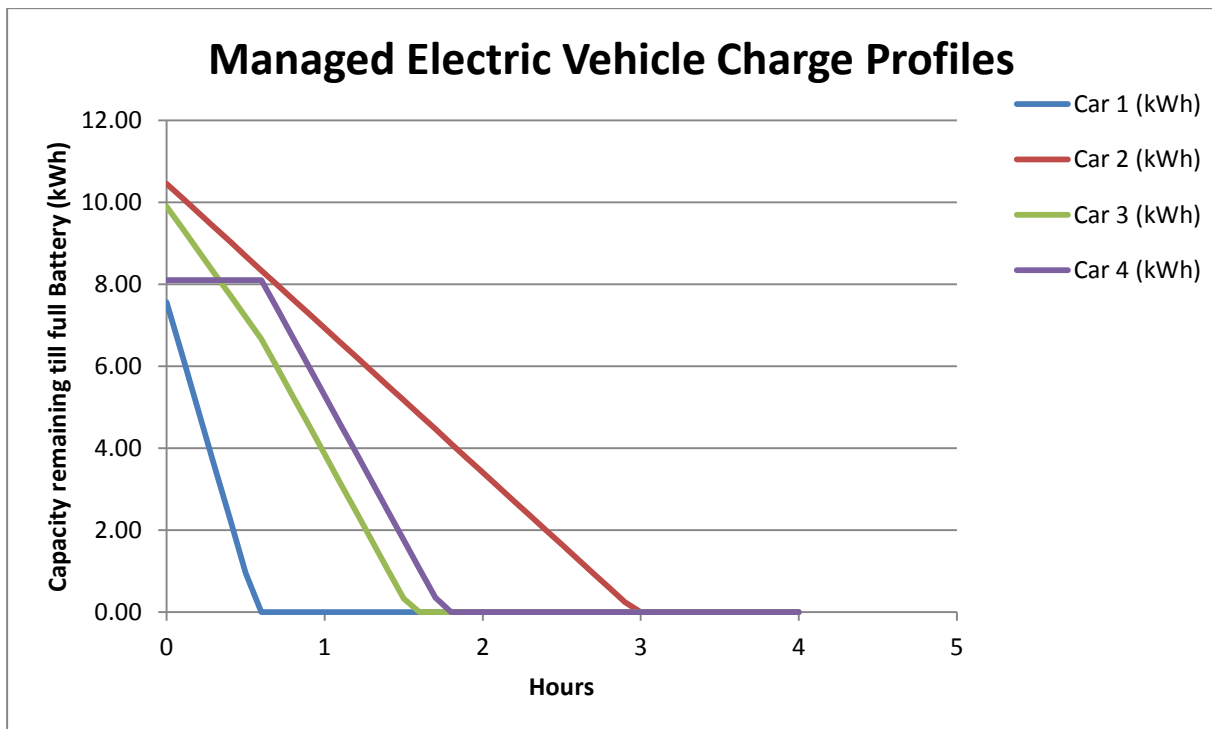
Average Off peak (kW)	22.05
Available for charging (kW)	22.11

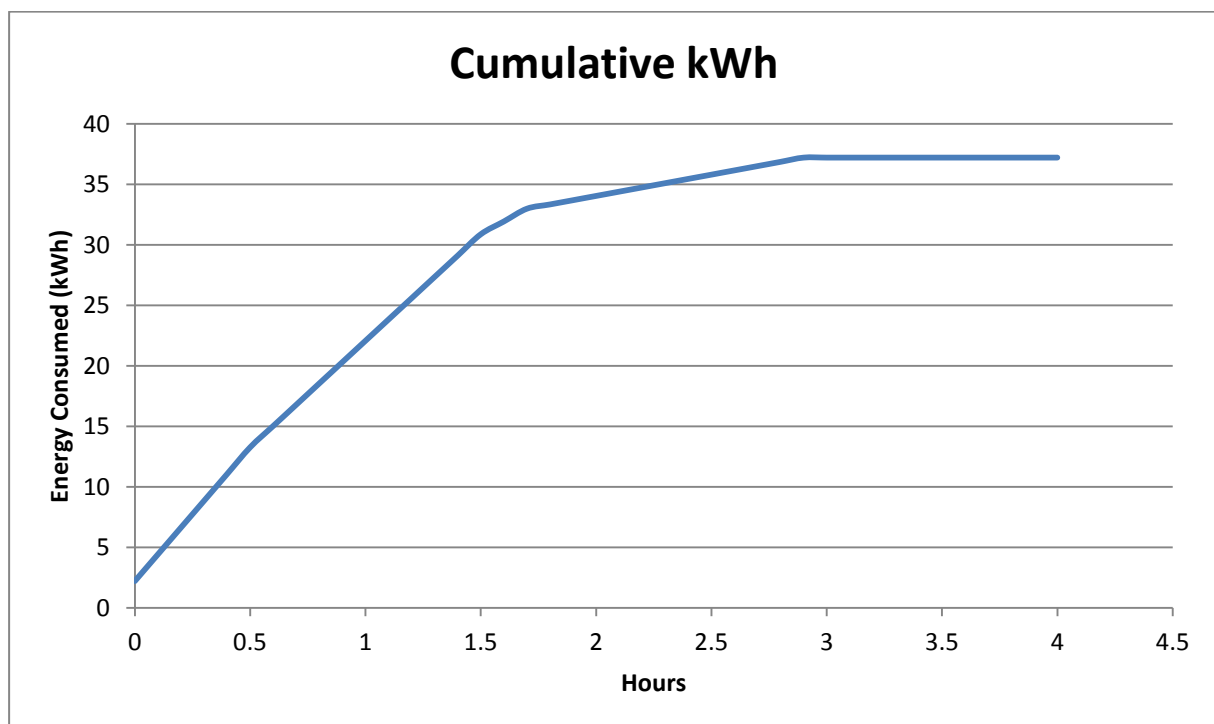
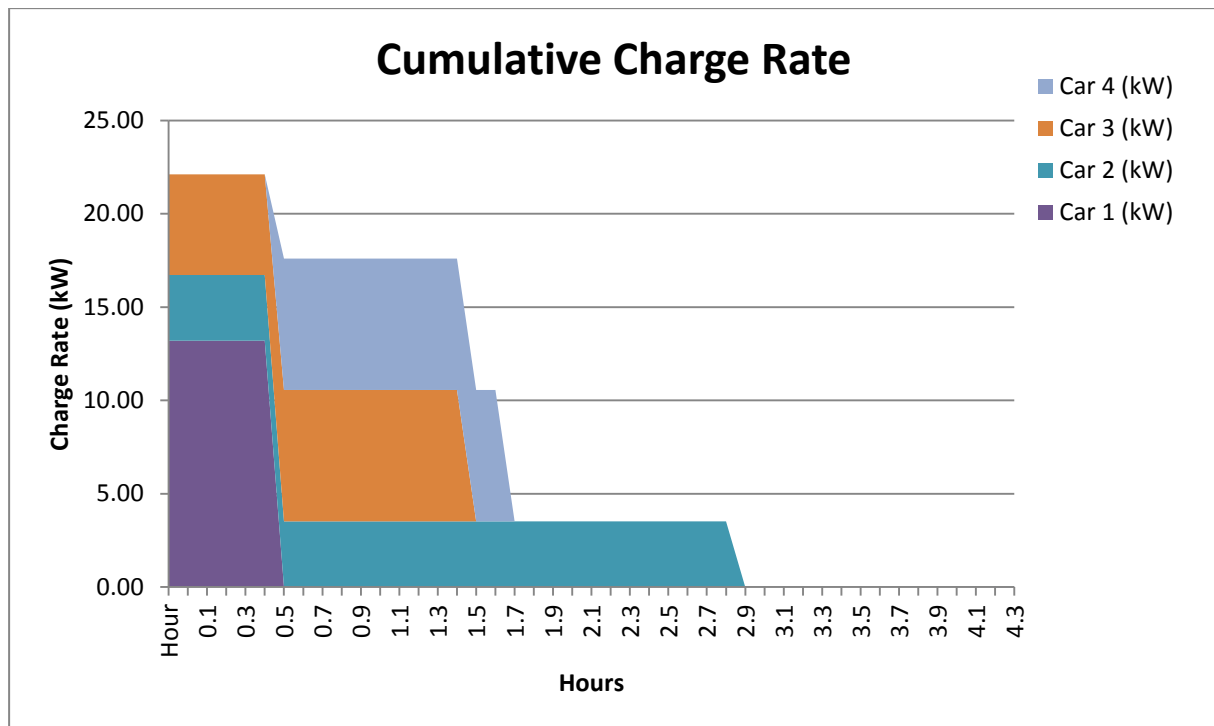
Charging capacity unmanaged	5	Based off available rate (kW)
Charging capacity managed	29	Based off available capacity (kWh)

8.3.2 Unmanaged Charging Model Results



8.3.3 Managed Charging Model Results



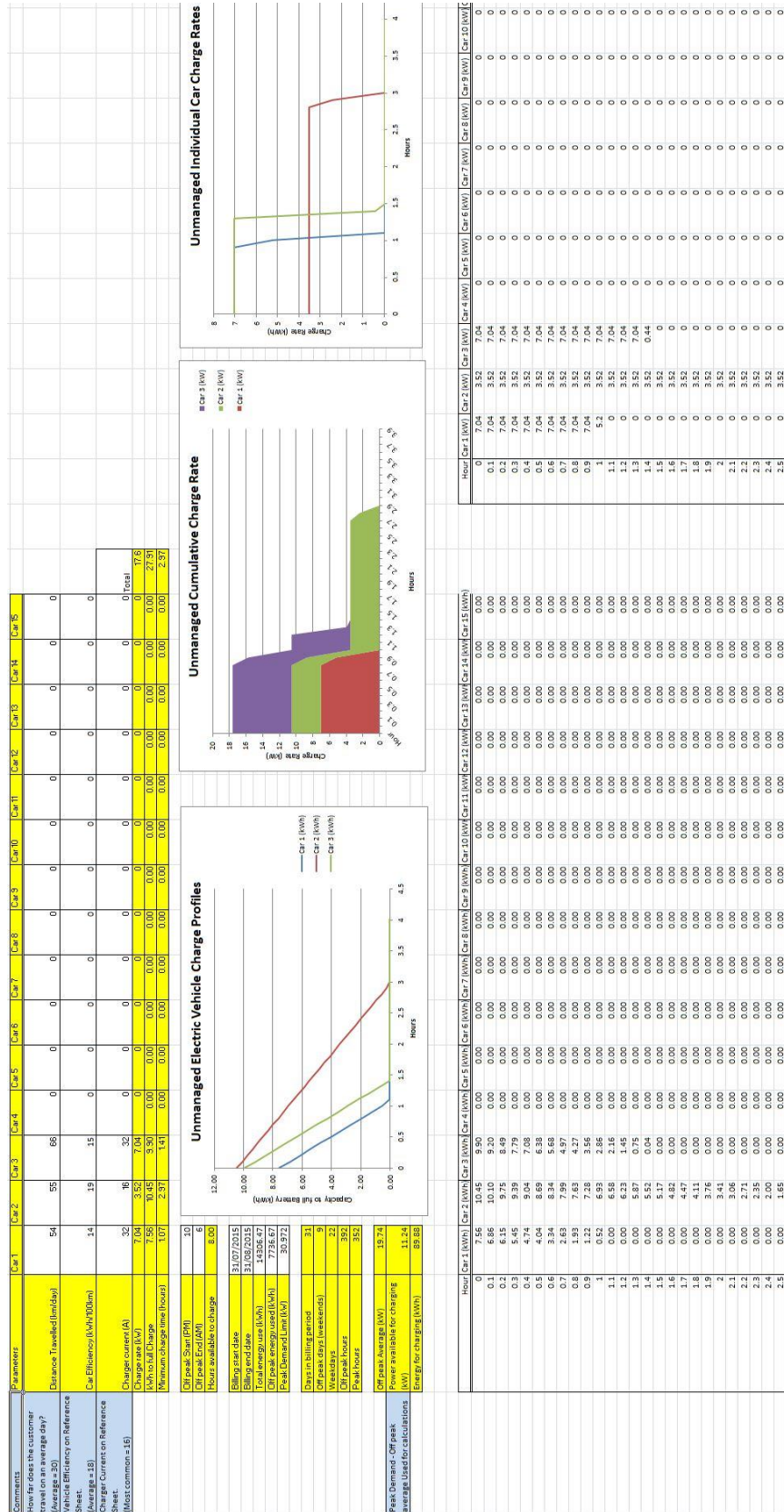


9 APPENDIX 2

9.1 Basic Charging Model Layout

Enter billing data into white cells		
Parameter		Comments / Average values
Distance Travelled (km/day)	30	30
Car Efficiency (kWh/100km)	18	18
Charger current (A)	16	16
Charging efficiency (%)	90	90
Charge rate (kW)	3.52	
kWh to full Charge	5.4	
Minimum charge time (hours)	1.53	
Off peak Start (PM)	10	10
Off peak End (AM)	6	6
Hours available to charge	8	
Billing start date	31/07/2015	DD/MM/YYYY
Billing end date	31/08/2015	DD/MM/YYYY
Total energy use (kWh)	14306.47	
Off peak energy used (kWh)	7736.67	
Peak Demand Limit (kW)	30.972	
Days in billing period	31	
Off peak days (weekends)	9	
Weekdays	22	
Off peak hours	392	
Peak hours	352	
Average Off peak (kW)	19.74	
Available for charging (kW)	11.24	
Charging capacity unmanaged	2	Based off available rate (kW)
Charging capacity managed	14	Based off available capacity (kWh)

9.2 Unmanaged Charging Model Layout



9.3 Managed Charging Model Layout

