Solar PVs to Charge EVs in Auckland –Potential for a Community Based Approach

Kiti Suomalainen, The University of Auckland, New Zealand
Basil Sharp, The University of Auckland, New Zealand

The Asian Conference on Sustainability, Energy & the Environment 2015
Official Conference Proceedings

Abstract
Auckland enjoys 2050 hours of sunshine annually, comparable to Melbourne (2100) and Istanbul (2026). Auckland Council is committed to a sustainable pathway in mobility and energy consumption, aiming at 40-50% of electric vehicle (EV) fleet and solar photovoltaic (PV) installations powering an equivalent of over 176 500 homes by 2040, among other sustainability targets. The general challenge of combining solar PV with EV investments for most Aucklanders is the mismatched timing of solar output (day time) and vehicle availability for home charging (night time). Technically this could be overcome by smart meters for PV installations at residential homes and charging points at commercial buildings, where the vehicle could be charged and differences between EV load and PV output accounted for.

To evaluate the potential for EVs charged by PVs in Auckland we have assessed the solar potential in a residential area in Auckland and compared that to typical EV battery sizes. We present the idea of a community based organisation for charging EVs with solar power, where the solar panels are installed at residential homes and the charging takes place at a parking location in the commercial centre of Auckland. With a community based approach - whether based on people working for the same company, people working in the same commercial building, or simply people using the same car park - some investment and transaction costs, as well as risk, can be shared, battery storage costs avoided and the learned know-how transmitted onwards to transform Auckland towards its sustainability targets.

Keywords: solar PV, electric vehicles, Auckland

Introduction

New Zealand has a long history of a highly renewable electricity sector, mainly due to large-scale hydro projects during the second half of the 20th century, and more recent growth in geothermal and wind energy. Current energy strategy focuses on economic growth and there are no economic incentives for renewable energy or low-carbon technologies in general. Yet, the government has a target to reach 90% renewable share of electricity from the current 70-75% share by 2025. The domestic renewable energy resources exist, and it has been shown that already consented projects would be sufficient to reach that target. However, demand has flattened and even decreased in the last five years, which has halted these projects. Transformation to electric mobility would imply three main opportunities for New Zealand: (1) an increase in domestic electricity demand, taking New Zealand closer to the 90% renewables target, (2) a decrease in dependence on imported crude oil, and (3) a direct reduction in greenhouse gases.

Auckland Council's Low Carbon Auckland report (2014) sets the 2040 sustainability targets for energy and transport in Auckland region. These targets include an equivalent of 176 565 homes power by solar PVs on buildings and 30-40% of the vehicle fleet to be electric, among many others. With these targets in mind, as many commute from residential areas to commercial areas, and park their vehicle at work for the day, solar power could be used to charge the electric vehicles (EV) at work during regular working hours.

To evaluate the feasibility for EVs charged by PVs in Auckland we have assessed the solar potential in a residential area in Auckland and compared that to typical EV battery sizes. We present the idea of a community based organisation for charging EVs with solar power, where the solar panels are installed at residential homes and the charging takes place at a parking location in the commercial centre of Auckland. We expect this approach would bring cost savings to the PV owners, as they would not need to install a battery system at home. In addition, the learned know-how could induce further EV and PV initiatives and contribute to transforming Auckland towards its sustainability targets.

Energy in New Zealand – Opportunity for electric mobility

New Zealand has a long history of producing a large share of its electricity from renewable resources, mainly due to large scale hydro developments in the second half of the 20th century. The renewables share of electricity was 75.1% in 2013. Due to this high share of renewable electricity, New Zealand is third in the world for percent renewables in total primary energy supply with 37% in 2012 (MBIE, 2013). This consists of 19% geothermal, 10% hydro and 8% other renewables (figure 1).

On the demand side, transport and the industrial sector consume the bulk of final energy, 37.6% and 34.7%, respectively. Although the electricity sector is largely renewable, the transport sector is dominated by oil consumption. New Zealand currently imports over twice the quantity of crude oil that it exports. At the same time the country has significant renewable energy resources available. This presents an opportunity for electrification of the transport sector, which implies both energy security in terms of reduced dependency on imported fuel and greenhouse gas abatement. In July2015 there were 660 electric vehicles registered in New Zealand (DriveElectric, 2015).

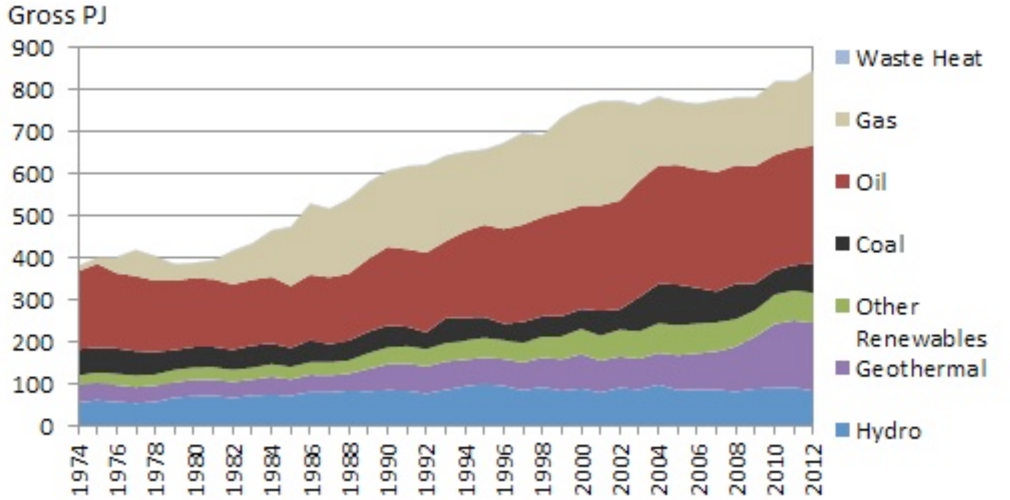

Figure 1: New Zealand's primary energy supply by source since 1974 (MBIE, 2013).

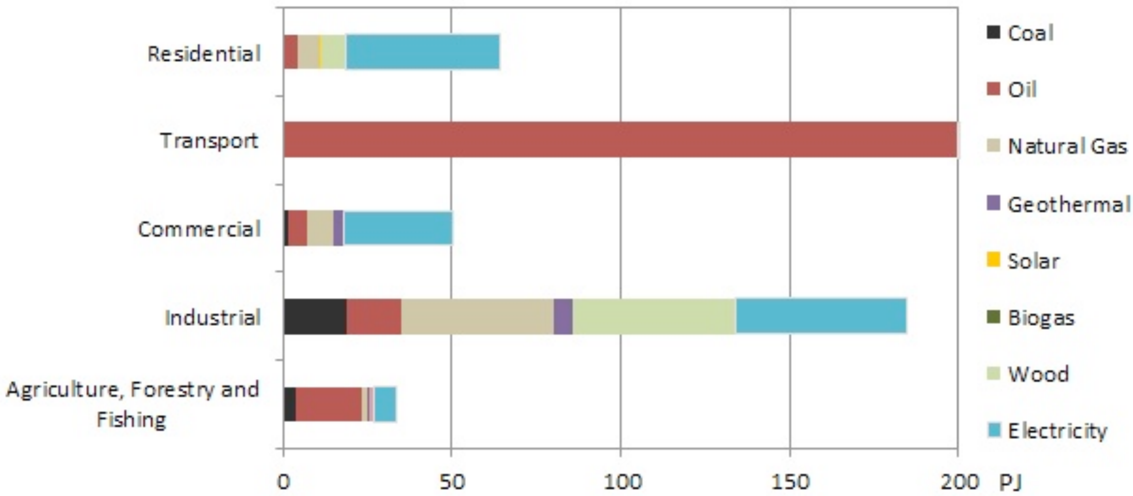

Figure 2: Primary energy consumption in New Zealand by energy source in 2012 (MBIE, 2013).

Electricity demand has flattened in the past decade and slightly dropped in the last couple of years due to decreased production at various industrial consumers (figure 3). Although wind and geothermal energy are the likely new future developments, major new investment (not already committed) is unlikely to occur until 2020.

New Zealand has an open, competitive electricity market (generation and retail separated by the wholesale market), while transmission and distribution are regulated natural monopolies.

Although the country has set an ambitious renewable energy target for the electricity sector – 90% renewable energy by 2025 – there are no quantitative targets for primary energy or the transport sector. Some of the main challenges for reaching this target, or any development towards a low carbon economy, include lack of policy support and geographic constraints. There is no national policy aimed to support this target. Renewable energy suppliers receive no feed-in tariffs or other direct incentives for low carbon technologies. However, already consented renewable energy projects add up to sufficient renewable energy supply to reach the 90% target, but currently these projects are not being built due to flattened demand. Also, as an island country, New Zealand has no opportunity to import or export power, meaning the variability of hydro, wind and solar power needs to be balanced nationally, posing an additional technical challenge.

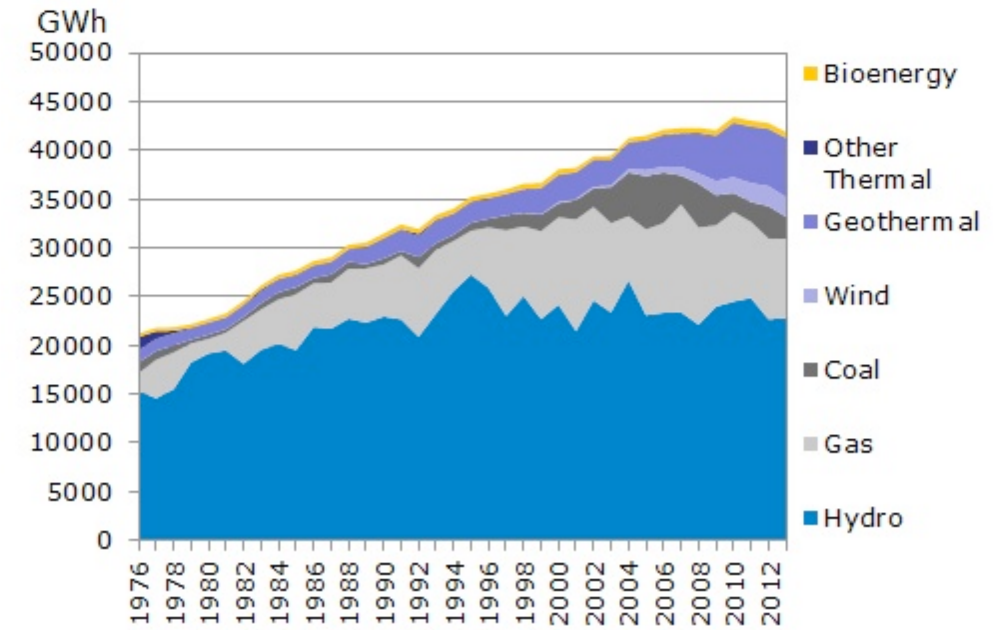

Figure 3: New Zealand's electricity supply by source from 1976 to 2013 (MBIE, 2013).

New Zealand's greenhouse gas (GHG) emissions were roughly 80 MtCO2-eq in 2013 (Ministry for the Environment, 2015). Energy accounts for 39% of the total GHG emissions, corresponding to 31.7 MtCO2-eq, second to agriculture (48%). Within energy, the transport sector shows the highest increase since 1990, from roughly 9 MtCO2-eq to 14 MtCO2-eq in 2013. New Zealand has one of the highest rates of car ownership in OECD countries and a relatively old vehicle fleet. This presents the opportunity for modernising the fleet where electric vehicles could play a significant role.

Solar potential in Auckland

A study by Byrd et al. (2013) on roof-top solar potential in Auckland showed that the low dense suburbia is the most efficient collector of solar energy in Auckland. They showed that enough excess electricity can be generated to power daily transport needs of suburbia and also contribute to peak daytime electrical loads in the city centre. A detached dwelling would consume less than half of its total demand during day-time, while a 3.5kW PV installation would be sufficient to supply the total demand. They concluded that a dispersed city is more efficient when distributed generation of electricity by PV is the main energy source and EVs are the means of transport.

The main problem with this concept is that during the day-time the supply system – the PV – sits on the rooftop of a residential home producing power, while the storage system – the EV – would typically be parked in the central business district (CBD), where most jobs are located.

Approach

To assess the suitability of using private electric vehicles to store excess solar energy from residential rooftops, we simulated scenarios of solar PV output with the following options:

- PV system size: 1 kW, 2 kW, 3 kW, 4 kW, 5 kW
- PV panel tilt: 15, 20, 25, 30, 35, 40, 45 degrees

We then compare the daily solar power output to residential electricity demand to estimate the daily excess solar power over a year in every scenario. By comparing these results to typical EV battery sizes, considering that the battery capacity is unlikely to be fully available for storing the solar power, we can evaluate the trade-offs of different configurations regarding system size, tilt and battery capacity.

Data and assumptions

To quantify the potential for rooftop PV systems on residential homes to charge EVs we make the following assumptions:

- PV panel: 8.33 m2/kW rated capacity,
- Total system efficiency from solar irradiation landing on panel to grid: 9%,
- North-facing panels,
- Location: Henderson, Auckland, approximately 20km from CBD, which corresponds to the average 40km of daily commute of Aucklanders.

Solar data from the National Institute of Water and Atmospheric Research (NIWA) solar tool SolarView (NIWA, 2015) was used to characterise the solar resource in Henderson. The tool gives a year of hourly data of solar irradiation per square meter, given a specified panel tilt. To show the impact of tilt on solar PV output, angles from 15 degrees to 45 degrees at 5 degree intervals, were used. To find the tilt that gave the maximum total annual output, the optimal tilt was narrowed down to 1 degree accuracy, which with SolarView was found to be 20 degrees. Using a different tool (e.g. PVWatts Calculator by NREL) can give a higher "optimal" tilt, and we believe the difference can come from the source of solar irradiation data, where theoretically calculated irradiation data taking into account latitude and mean atmospheric conditions would not take the occurrence or timing of clouds into account, whereas SolarView uses data measured at ground level data that will reflect any existing cloud patterns as well.

To characterise the electricity demand of a residential household we use metered hourly electricity demand data (EA, 2013) from a node in the residential area of Henderson, Auckland, and scale the values to represent the approximate average annual household demand in New Zealand, 8000 kWh. The data spans the years 2007 to 2012, giving six full years of hourly data.

EV battery storage capacity and charging options

High cost and low energy density of EV batteries have been the main challenge in developing EVs for commercialisation (CAENZ, 2010). Lithium-ion batteries have been the common battery type, with an energy density of about 100 Wh/kg. The battery system of an EV currently weighs roughly 150-250 kg, giving a typical capacity of 15-25 kWh. At the higher end, the Tesla Roadster has a battery weight of 450 kg and with a stated energy density of 118 Wh/kg, a battery capacity of 53 kWh. Table 1 give the currently available EV models in New Zealand, and their corresponding battery capacities (we acknowledge that the list is soon outdated with new models entering the market):

Table 1: Available electric vehicles in New Zealand, and their battery capacity.

	kWh
Audi A3 e-tron	26.5
BMW i3	22
Holden Volt	16
Mitsubishi i-MiEV	16
Nissan Leaf	24

This gives a rough idea of storage capacity for excess solar power. However, one must recognise that in most cases only a portion of the battery capacity would be available for this. At a minimum, the owner is likely to have enough power to return home after work, without charging during the day. Hence the actual capacity available for solar storage would depend on commuting distance and behavioural patterns, among others.

Table 2 gives the most common charging categories and general infrastructure requirements. We base our scenarios on the second and third options (4 kW and 13 kW, respectively), considering they are the likely options for our application. The first option could be unsafe and the last would be too expensive considering our aim to save on total costs (RMI, 2015).

Table 2: Charging mode options

	Can be used with typical existing household wiring and infrastructure	Requires dedicated charging equipment to be installed
• Slow charging [2-3kW] • Standard household socket • Standard lead	√	
• Slow charging [4-5kW] • Standard household socket • Lead equipped with protective device	√	
• Slow or fast charging [13kW] • Dedicated EV charging installation • Equipped with a protection function		√
• Fast charging [78kW] • External charger		√

Results

Solar PV output

Figure 4 shows the solar output with the above assumptions for each month for the various tilt angles. For each month, the daily mean output during non-zero hours was used, giving the range depicted by the boxplot: the thick horizontal line gives the mean, the rectangle and the whiskers represent the 0.25 and 0.75, and 0.10 and 0.90 quantiles, respectively. The annual output given on the top of each subplot show that the 20 degree tilt gives the highest annual output and the 40 degree tilt gives the lowest (45 degrees gives an even lower annual output, but is not shown in this figure). However, the impact of the tilt on monthly output is quite clear: the low tilts maximise output during summer months whereas the higher tilt captures more solar irradiation during winter months when the sun is closer to the horizon at noon, but captures less solar irradiation during summer. The higher tilt thus gives a more even annual pattern of solar output, although at the expense of total output.

Figure 5 gives the hourly output of a PV system in Henderson for three different tilts (15, 25 and 45 degrees) and the months of January (summer) and July (winter).Comparing the tilts it can be seen that in summer the higher tilt gives a clearly lower output over the day, whereas in winter a higher output can be expected.

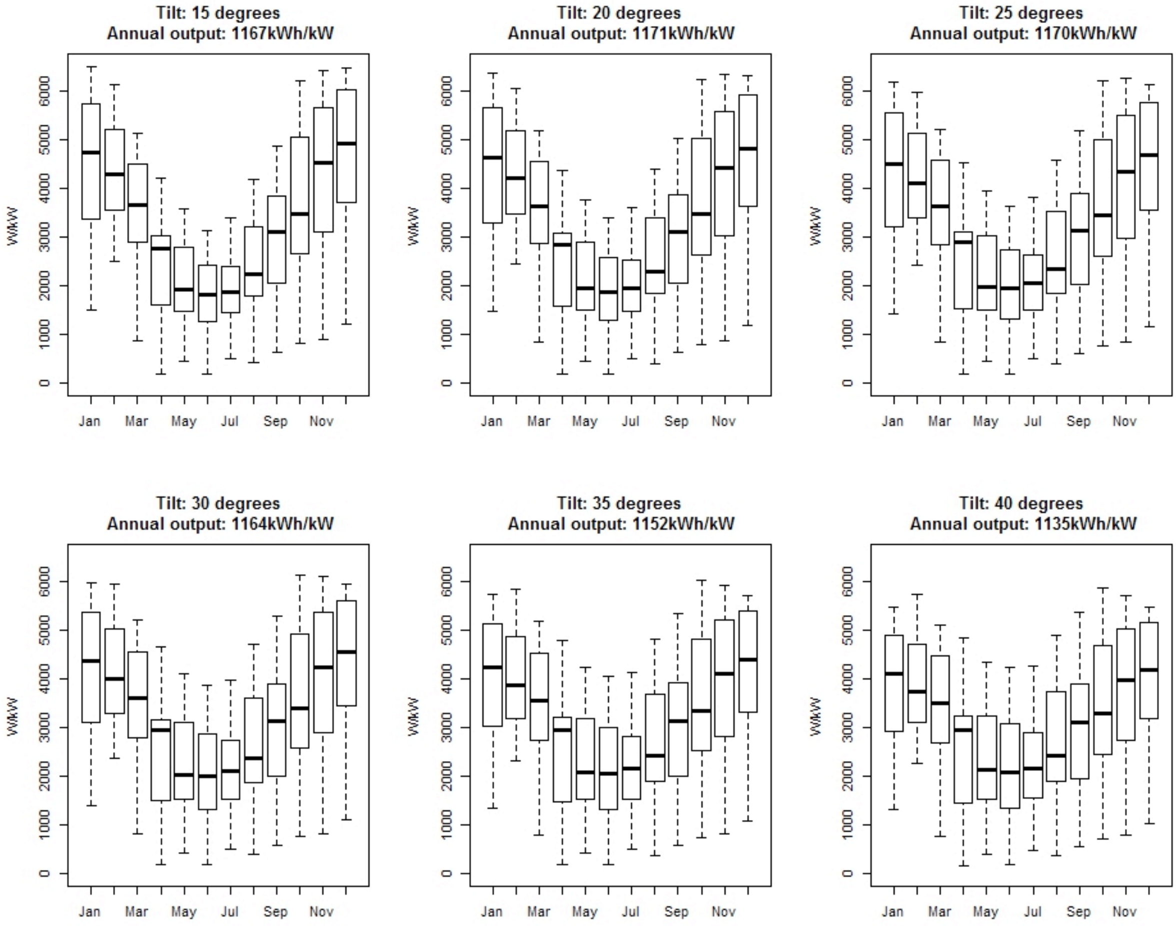

Figure 4: A year of hourly solar PV output data plotted at six different panel tilts. The mean daily output was calculated over non-zero output hours, represented in the boxplot for each month.

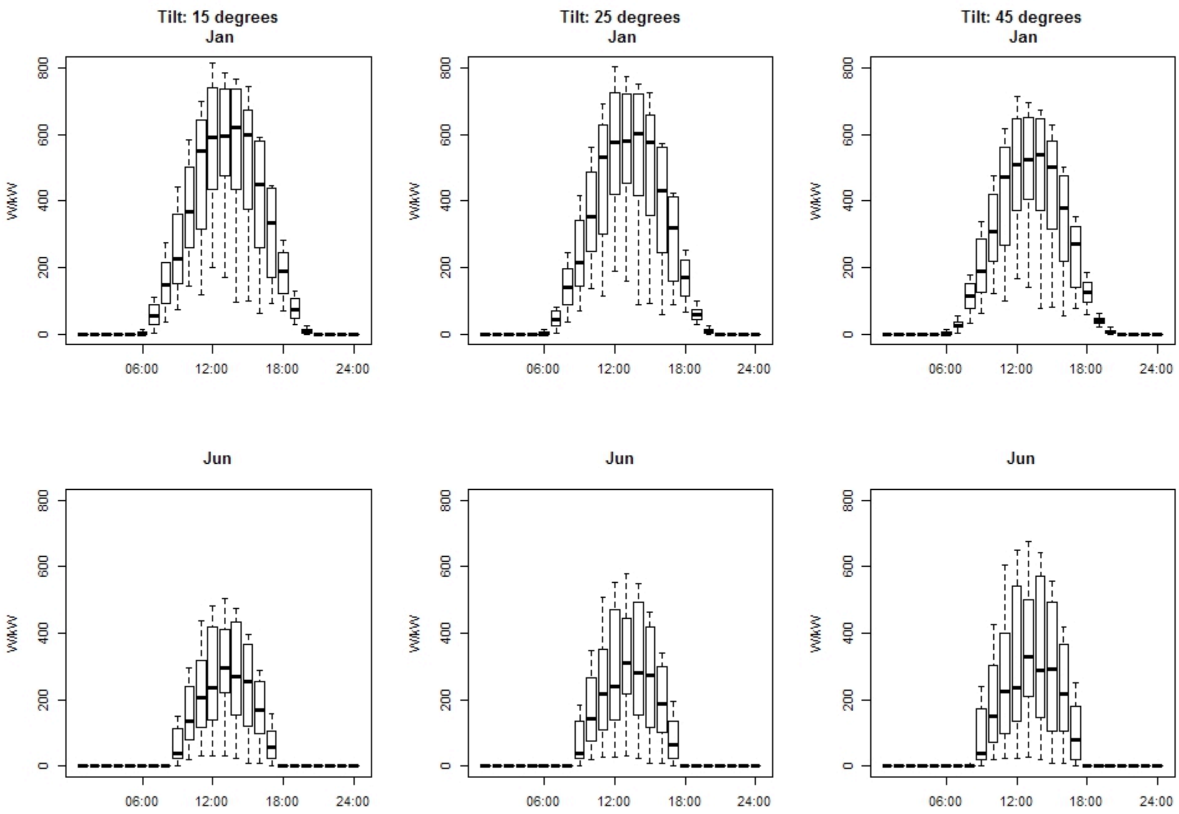

Figure 5: Hourly output of a PV system in Henderson, plotted for three different tilts (columns) and for January (top row) and July (bottom row).

Residential electricity demand

Figure 6 gives the average monthly household electricity demand over six years. Demand is significantly higher during winter months due to heating. Inter-annual variability is relatively small. Compared to the seasonal pattern of the solar PV system, the peaks are approximately 6 months out of phase as solar PV output peaks in summer whereas electricity demand leaks in winter. This could advocate for a higher tilt angle, to capture more solar irradiation during the winter months.

Figure 7 gives the daily electricity demand pattern for a summer day (hourly data for January) and a winter day (hourly data for June). The demand in summer is relatively flat during the day and decreases for the night. In winter, demand is higher and there are clear demand peaks in the morning and in the evening. Although solar power can be available for the increased day-time consumption, it will not be directly available for the evening peak in winter or the lower demand at night.

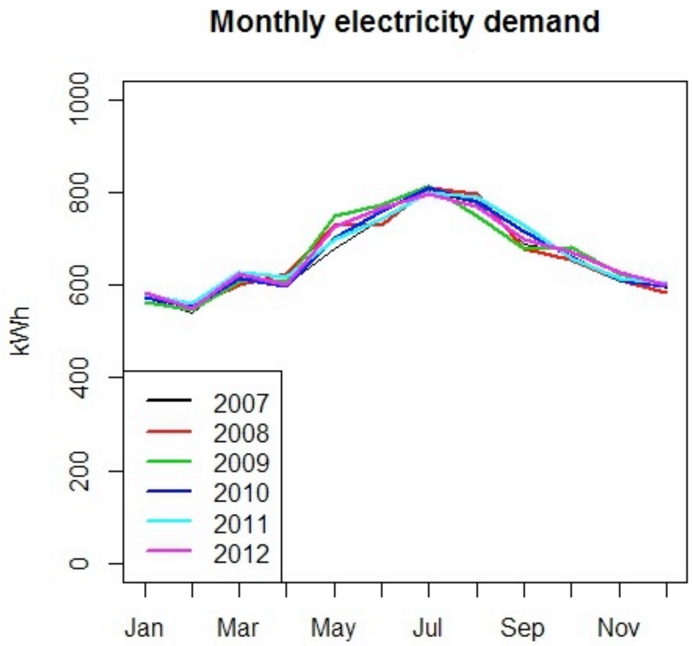

Figure 6: Average monthly household electricity demand over six years.

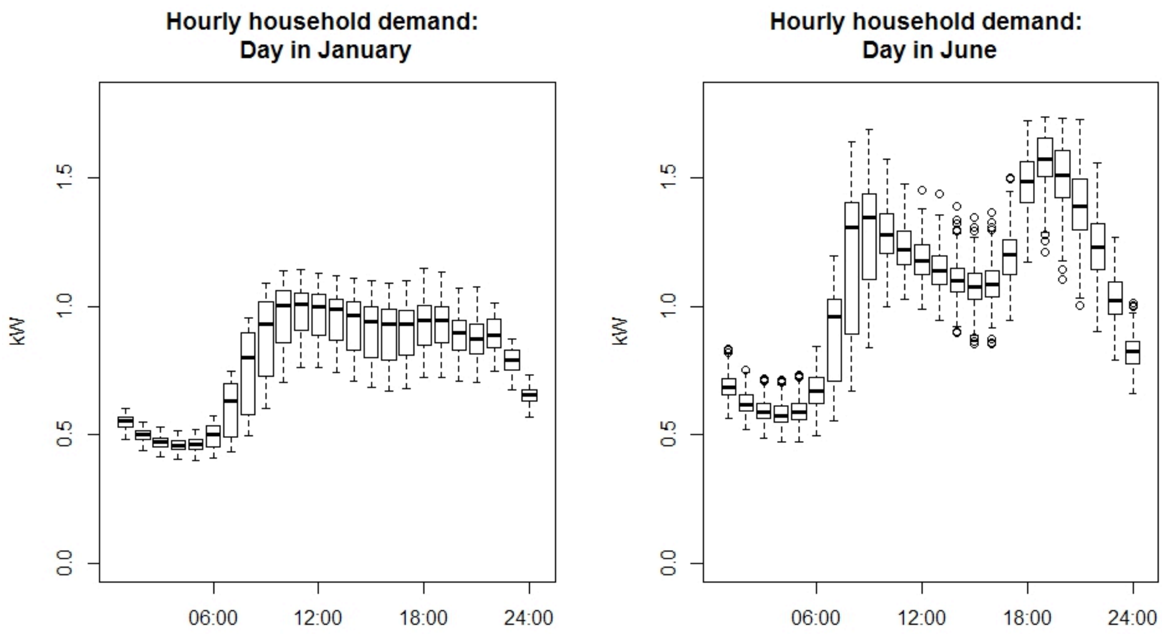

Figure 7: Daily electricity demand patterns for a household for a day in January versus a day in June.

To quantify the daily storage requirements from a given size PV system, the hourly demand was subtracted from the hourly output of the PV system. Figures 8 and 9 give the results for a 2 kW and 5 kW system, respectively. Results are shown for tilt angles of 15, 25 and 45 degrees (columns) and for January (top row) and June (bottom row). Figure 8 shows that for a 2 kW system the excess solar power output is less than 1 kW in summer and it is rare to get any excess power in winter. As figure 9 shows, the 5 kW system will provide excess solar power even in winter, although less so with a smaller tilt. In summer the excess power reaches approximately 2 kW on average during the peak. As can be expected, the difference is always negative during the night and power from the grid will be required during those hours.

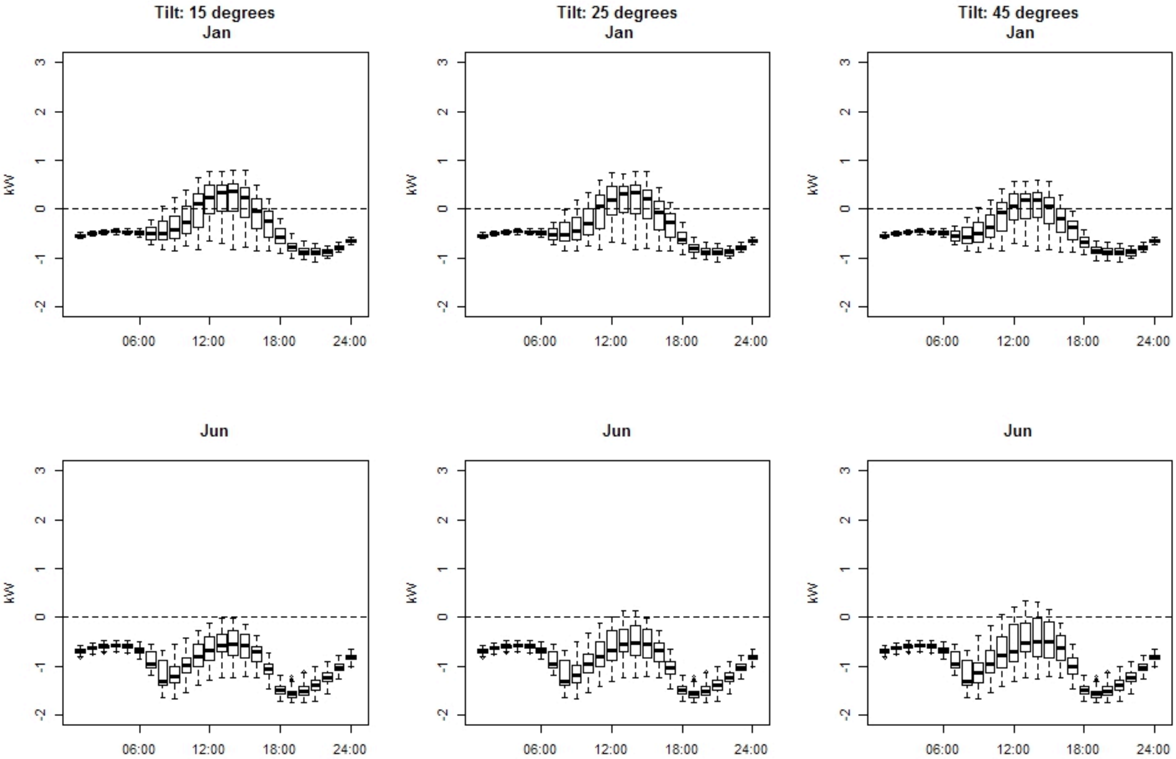

Figure 8: PV energy storage requirements for a 2 kW PV system.

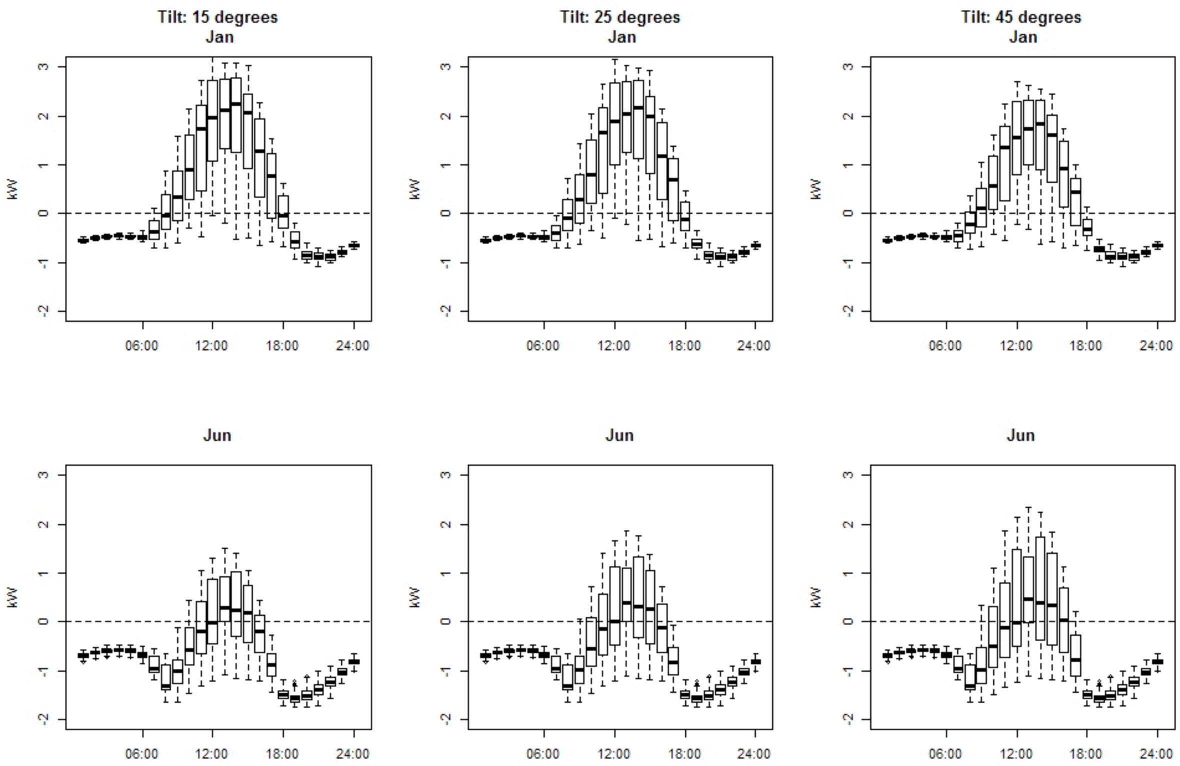

Figure 9: PV energy storage requirements for a 5 kW PV system.

Table 3 gives the full results for total annual storage needs (excess solar power) and required power from the grid for the different tilts and system sizes. Interestingly, the tilt angle that gives the maximum annual output (20 degrees), gives the lowest grid power requirements only for 1 kW and 2 kW system sizes. For bigger PV system sizes, the 15 degree tilt gives the lowest requirements for power from the grid. This implies that the low 15 degree tilt might be a better match with the demand pattern than higher tilt angles, and thus the optimal angle for a residential PV system, for larger systems. For a small system where all solar power is directly consumed, maximising total annual output would be the optimal solution.

Table 4 gives selected results for the mean daily storage need on average and for the months with highest (January) and lowest (June) PV outputs. The difference between the mean and maximum values is very important when assessing whether the EV battery system is sufficient to be used as storage for excess solar power. These results highlight the trade-off between maximising total solar output (20 degree tilt) and seeking a balance between summer and winter output (45 degree tilt); a slightly smaller output of the latter in summer is balanced by a slightly higher output in winter. Also the maximum values are smaller in with the 45 degree tilt.

Table 3: Annual storage needs vs. grid needs (in parenthesis).

[kWh]	Tilt 15	Tilt 20	Tilt 25	Tilt 30	Tilt 35	Tilt 40	Tilt 45
1 kW	0.2 *(6835)*	0.2 *(6831)*	0.1 *(6832)*	0.0 *(6838)*	0.0 *(6850)*	0.0 *(6867)*	0.0 *(6889)*
2 kW	201 *(5868)*	203 *(5862)*	201 *(5863)*	195 *(5869)*	185 *(5883)*	171 *(5903)*	153 *(5929)*
3 kW	820 *(5320)*	833 *(5321)*	836 *(5328)*	829 *(5340)*	810 *(5356)*	780 *(5377)*	740 *(5403)*
4 kW	1655 *(4988)*	1677 *(4994)*	1683 *(5004)*	1671 *(5019)*	1643 *(5037)*	1596 *(5058)*	1533 *(5083)*
5 kW	2601 *(4768)*	2630 *(4776)*	2637 *(4788)*	2620 *(4804)*	2580 *(4823)*	2517 *(4844)*	2431 *(4867)*

Table 4: Average daily storage needs and maximum daily storage needs.

	3 kW		4 kW		5 kW	
[kWh]	Tilt 20	Tilt 45	Tilt 20	Tilt 45	Tilt 20	Tilt 45
Annual average (max)	2.3 *(10.4)*	2.0 *(7.7)*	4.6 *(16.6)*	4.2 *(13.0)*	7.2 *(22.7)*	6.7 *(18.4)*
January average (max)	4.7 *(10.4)*	3.2 *(7.5)*	8.4 *(16.6)*	6.2 *(12.3)*	12.4 *(22.7)*	9.5 *(17.3)*
June average (max)	0.3 *(2.2)*	0.9 *(4.6)*	1.2 *(5.2)*	2.2 *(8.6)*	2.3 *(8.3)*	3.7 *(12.9)*

Charging time of excess solar power to EV

Figures 10 and 11 show the charging time of excess solar power to an EV with fast and slow charging as a function of panel tilt and system size, respectively. Figure 10 shows that in general charging time decreases with tilt, as excess power declines, except in winter when the higher tilts capture more solar irradiation. Also, maximum annual output coincides with the maximum output of January for most tilt angles. However, for 35 degrees or higher, the maximum output is not in January. For a 4 kW system, the highest charging time by slow charging reaches approximately 4 hours, which is still a reasonable time for charging the EV while at work. For a fast charger the highest charging time is roughly 1 hour 10 minutes. The average charging time in January is approximately 2 hours for low tilts using a slow charger, and less than 40 minutes with a fast charger.

Figure 11 shows a steep incline of charging time with system size. The maximum charging time with a slow charger is over 5 hours for a 5 kW system. However, the average charging time is significantly lower, at approximately 1 hour 40 minutes, and approximately 4 hours in summer. With a higher tilt angle, charging times are lowered, as seen in the top right sub-plot. Finally, as expected, charging times are significantly reduced with fast charging, as the bottom row sub-plots reveal.

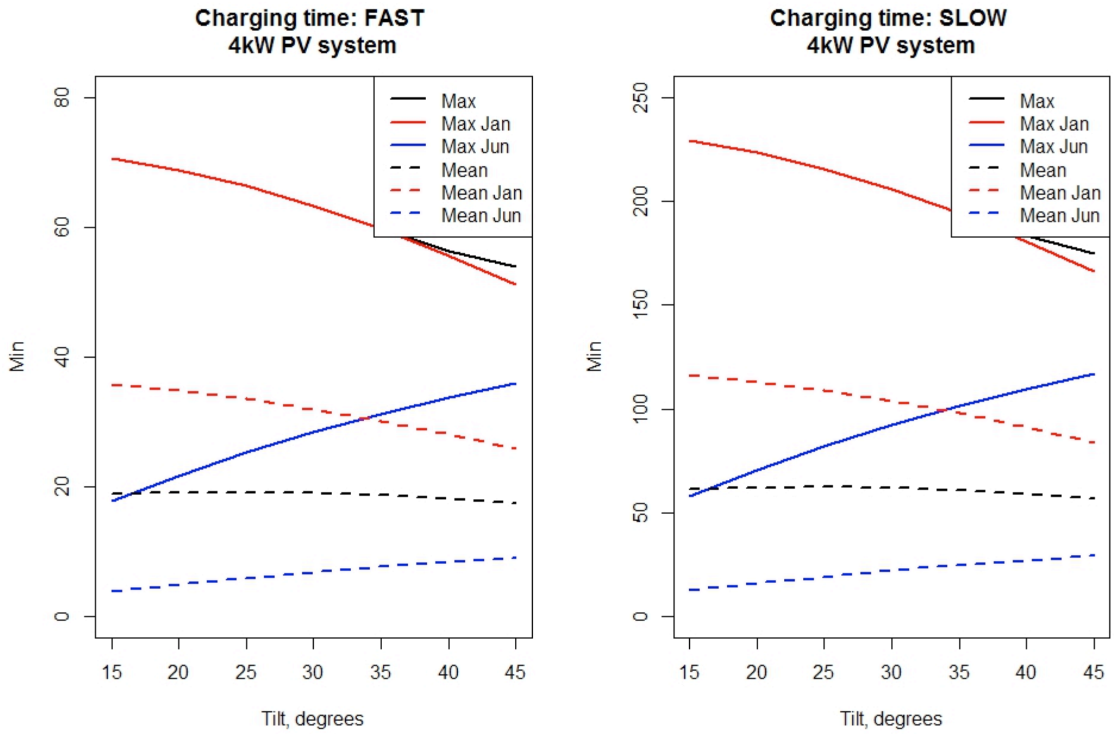

Figure 10: Charging time of excess solar power as a function of panel tilt.

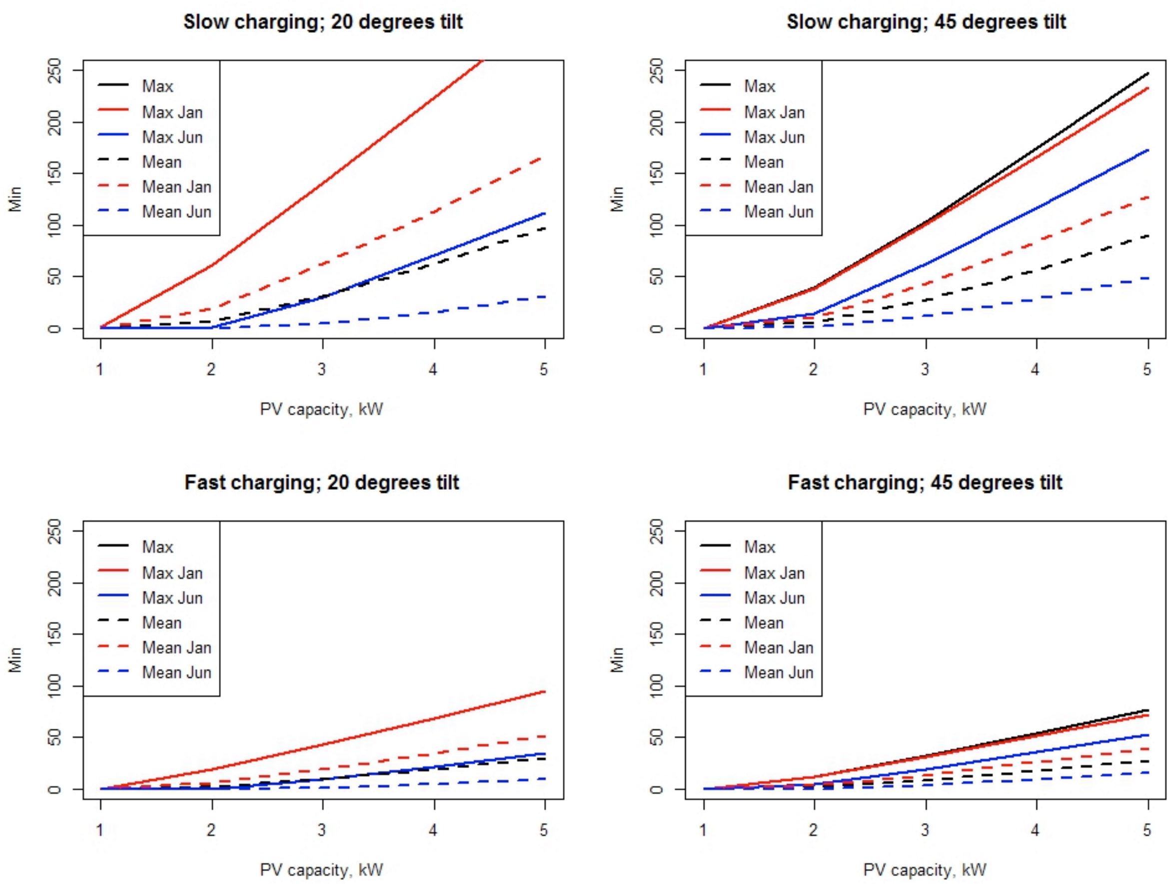

Figure 11: Charging time of excess solar power as a function of PV system size.

Discussion: A community based approach

The results show that in terms of PV system scale and typical EV battery sizes, it is feasible to use the EV battery to store excess solar power during the day. It is currently not possible mainly due to two obstacles: the lack of charging infrastructure at parking facilities in the CBD and the lack of a pricing mechanism to account charged power to generated solar output and take in to account any differences.
In this paper we explore whether a community based approach could be used to overcome those barriers.

What is it?

- EV owners co-finance a charging station at their parking location, and eliminate need for a battery system at home
- Pricing mechanism agreed with retailer or lines company
- Smart meters at PV systems and EV charging allow for transfer of "solar credits" and accounting for deviations
- Slow charging is an inexpensive, technically feasible option, with multiple outlets possible

Who is it for?

- "First-movers" with both solar PV and an EV
- Parking in same location most days

Challenges

- Cost of billing: the relatively small transactions may make the overall cost of the pricing mechanism unviable economically, especially with small numbers of clients
- The community needs to be flexible and open for newcomers, which may require a more complex definition of the agreement, than an informal arrangement between a few EV owners and the parking facility manager.

Opportunities

- Roll-out of EV charging points
- Experience gain through learning with small numbers
- Eventually a network of chargers, possibility to charge at different locations, that could expand from a small community to a nation-wide association
- Independent of national policy

Conclusions

In this paper we have assessed the rationale of using electric vehicles to store excess solar power in Auckland. Electric mobility provides a significant option for New Zealand to reduce GHG emissions, as the electricity mix is already highly renewable and likely to become more so, and move from imported oil to domestic renewable energy resources.

In the absence of national policy incentives, the deployment of EVs relies on local level proactivity, at the level of municipalities, the private sector and individual initiatives or “first movers”. With the cost of solar power decreasing, Auckland has seen a steady growth of solar installations. We have showed that the scale of daily excess solar power could generally be stored in the battery of currently available EVs during working hours, even with a slow charger.

Community based approaches can lower initial costs and promote both the installation of solar power systems and the uptake of EVs in its initial steps of deployment in New Zealand. This would provide valuable knowledge gain in the community and help Auckland transform towards a low-carbon society.

References

Auckland Council, 2014, *Low Carbon Auckland, Auckland's Energy Resilience and Low Carbon Action Plan,* http://www.aucklandcouncil.govt.nz/EN/planspoliciesprojects/plansstrategies/theaucklandplan/energyresiliencelowcarbonactionplan/Pages/home.aspx, accessed in July 2015.

Byrd, H., Ho, A., Sharp, B., Kumar-Nair, N., 2013. *Measuring the solar potential of a city and its implications for energy policy*, Energy Policy, Volume 61, pages 944-952.

Electricity Authority (EA), Centralised Dataset, version March 2013.

DriveElectric, Association for the Promotion of Electric Vehicles, www.driveelectric.org.nz, last accessed 02.07.2015.

Ministry of Business, Innovation and Employment (MBIE), 2014. *Energy Data File*, http://www.med.govt.nz/sectors-industries/energy/energy-modelling/data, last accessed in July 2015

Ministry for the Environment, 2015, *New Zealand's GHG Inventory 1990-2013*.

New Zealand Centre for Advanced Engineering (CAENZ), 2010. *Electric Vehicles, Impacts on New Zealand's Electricity System*, Technical Report.

National Institute of Water and Atmospheric Research (NIWA), *SolarView,* https://www.niwa.co.nz/our-services/online-services/solarview, last accessed July 2015.

Rocky Mountain Institute (RMI), blog.rmi.org/blog_2014_04_29_pulling_back_the_veil_on_ev_charging_station_costs, accessed in May 2015.

Contact email: k.suomalainen@auckland.ac.nz