Submission No 30

ELECTRIC BUSES IN REGIONAL AND METROPOLITAN PUBLIC TRANSPORT NETWORKS IN NSW

Organisation: Centre for Energy and Environmental Markets, UNSW

Date Received: 20 December 2019

Centre for Energy and
Environmental Markets

INQUIRY INTO ELECTRIC BUSES IN REGIONAL AND METROPOLITAN PUBLIC TRANSPORT NETWORKS IN NSW

Submission in response to the Committee on Transport and Infrastructure

by
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December 2019

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About CEEM

The UNSW Centre for Energy and Environmental Markets (CEEM) undertakes interdisciplinary research in the design, analysis and performance monitoring of energy and environmental markets and their associated policy frameworks. CEEM brings together UNSW researchers from the Faculty of Engineering, the Australian School of Business, the Faculty of Arts and Social Sciences, the CRC for Low Carbon Living, the Faculty of Built Environment and the Faculty of Law, working alongside a number of Australian and International partners.

CEEM's research focuses on the challenges and opportunities of clean energy transition within market-oriented electricity industries. Key aspects of this transition are the integration of large-scale renewable technologies and distributed energy technologies – generation, storage and 'smart' loads – into the electricity industry. Facilitating this integration requires appropriate spot, ancillary and forward wholesale electricity markets, retail markets, monopoly network regulation and broader energy and climate policies.

Electric Vehicles are a vitally important technology for low carbon energy transition and CEEM has been exploring the opportunities and challenges they raise for the electricity industry for over a decade. More details of this work can be found at the Centre website – www.ceem.unsw.edu.au.

We welcome comments, suggestions and corrections on this submission, and all our work in the area. Please contact Associate Professor Iain MacGill, Joint Director of the Centre at i.macgill@unsw.edu.au for inquiries about CEEM, or Katelyn Purnell at k.purnell@unsw.edu.au for specific queries about this submission.

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Introduction

CEEM welcomes the opportunity to contribute to this important Parliament inquiry regarding the great opportunities, yet also challenges, that accelerated electric buses uptake offers New South Wales. Battery Electric Buses (BEBs) are a solution to a myriad of existing problems; greenhouse emissions from transport, local air and noise pollution, traffic congestion and energy security. We applaud this initiative and recent announcements made by the NSW Transport Minister to electrify metropolitan bus fleets.

BEB deployment is growing rapidly in many jurisdictions worldwide, with a growing number of cities and countries declaring their intent to shift towards 100% electrification of transport. Some public transport is already electric, and buses are an obvious opportunity. In other jurisdictions of course, electric trolley buses have been operating for many decades. Buses in metropolitan areas seem particularly well suited to electrification given their limited area of operation and hence charging options, duty cycle with frequent stopping and starting that is very well suited to electric motor traction, and present reliance on highly polluting and noisy diesel engines.

Recent progress in EV technology and deployment is happening during a time of unprecedented change in the electricity sector, as new technologies and business models create opportunities for consumers to meaningfully participate in the electricity sector. Key amongst these technologies are a range of distributed energy resources (DERs), including rooftop PV and battery energy storage as well as 'smart loads'. BEBs represent a particularly promising electricity industry resource given the significant energy storage they will have, and the flexibility that this offers.

Appropriate charging scheduling design is key to maximising the benefits and minimising the costs and risks of BEB uptake

It is important to consider BEB adoption in this context. In addition to a transportation method, BEBs represent a major new load in the low/medium voltage distribution grid. A very large bus depot such as Ryde alone (~320 buses) could have a combined battery capacity as large as 50MWh[1] or more, and could add ~7MW instantaneous demand at the depot if charging is poorly managed[2].

Electricity tariff and incentive design is one key area of market design that needs attention with increasing electric vehicle penetration. Uncontrolled charging at high penetrations have the potential to exacerbate electricity network peaks, likely requiring network and generation investment that will increase electricity costs for consumers. We need to carefully consider how we design bus charging scheduling and electricity tariffs to prevent adding additional stress on the grid during network peak times. A flat rate tariff alone will not incentivise this, while time-of-use tariffs may create their own challenges by tightly correlating charging of EVs at times where the tariff changes.

[1] For scale, Australia's largest battery installation, the Hornsdale Power Reserve, is 129MWh.

[2] See question 2

At high levels of electrification, the combined NSW bus fleet could, however, also represent one the largest collections of centrally controlled energy storage in Australia. If even 10% of the total state bus fleet capacity was available for local grid support, this might represent the equivalent of three Tesla big batteries (400MWh of storage). This BEB DER could support minimisation of peak loads, ramping requirements and grid stability. This signals the need for more sophisticated retail market arrangements and well-informed incentives. We would argue that the task of designing such arrangements would ideally be undertaken through the use of open-sourced data and tools.

For the rest of our submission we address the specific questions posed by the Committee on Transport and Infrastructure ('the Committee') in its Terms of Reference, dated 23 October 2019.

We would again like to congratulate the NSW Government on this inquiry, and thank you for the opportunity to make a submission. We would of course welcome any opportunity to further contribute to the efforts of the Committee in this area.

Q1 – Benefits and Limitations

Question 1: Benefits of electric buses and factors that limit their wider uptake

NSW had 27,605 buses on register in January 2019 [1] which travelled ~634 million km in 2017-2018 [2]. Most of this distance was covered by route service buses (41%), followed by dedicated school bus services (23%) and charter services (18%) [2]. Transitioning from the predominately diesel legacy fleet to electric would reduce local particulate emissions, greenhouse gas emissions, noise pollution and reduce operational costs for the fleet operators. They will, however, significantly increase electricity demand in the local distribution networks where the depots are located, or where other charging infrastructure is located.

Environmental benefits

Transport is responsible for approximately 21% of the total Greenhouse Gas Emissions in NSW [3] (28MT$CO_{2\text{-eq}}$ /annum). NSW buses emitted approximately 0.44 MT$CO_{2\text{-eq}}$ [3] in 2017/18. While this is only approximately ~2% of annual NSW transport emissions, it is the equivalent of the emissions of ~135,000 private cars[4].

At current average diesel fuel and NSW electricity generation intensities, BEBs are already better from a carbon emission perspective. Table 1 compares the emissions of diesel and electric municipal buses. Depending on the fuel efficiency of the two vehicles, a BEB would emit 10-30% less CO_2 / annum compared to the diesel alternative in NSW.

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[3] Taking emission factors of 67.75kgCO2/GJ diesel and 69.7kgCO2/GJ gasoline from [4] and fuel consumption from [2]

[4] Taking the average private car as travelling ~12,600km/y with 10.8L/100km intensity [2]

As the energy sector transitions to low carbon renewable energy generation, the carbon reduction scope for BEBs increases. There are opportunities to sign PPAs with renewable projects in NSW to further offset associated emissions. If that energy was procured from on-site renewable generation (i.e. solar PV on either the depot or the buses themselves), fuel costs would similarly decrease.

Tailpipe emissions, and noise pollution are significantly reduced under electric drive trains, reducing local pollution in cities and the associated healthcare and productivity costs.

Cost Implications on the Fleet Operator

BEBs, like most electric vehicles, currently are at a capital cost premium to ICE vehicles, but are consistently decreasing. Projections from Bloomberg New Energy Finance project cost parity for the buses by 2030, and suggest currently BEBs are ~1.5x the capital cost of a new diesel bus in North American markets [5]. In addition to the vehicles' cost premium, drivers require additional training for the vehicle, procurement time is often longer and repairing vehicles is somewhat more difficult due to limited skilled repair persons at present. The transition to BEBs will incur additional costs such as rescheduling routes to account for additional charging times, limited charging equipment as well as reconfiguring the depot to allow for access to charging equipment.

The increased costs are balanced by the decreased maintenance and fuel costs in operation. Table 1 shows indicative fuel cost reductions of 40-60% for BEBs based on average retail diesel and electricity rates in NSW and assuming a retail flat tariff.

Table 1: Diesel and Electric Bus Comparisons

	Diesel	Electric
Fuel Intensity (/km)	0.5 - 0.6 L	1-1.5kWh[5]
Average daily distance (km)	90	
Daily fuel consumption	45-55 L	90-135 kWh
Carbon Emissions		
CO_2 intensity of fuel ($kgCO_2$)	2.24/L	0.82/kWh
$kgCO_2$ / bus / day	100 – 125	70 – 110
$kgCO_2$ / bus / day with 100% Renewable Energy	100 – 125	0
Fuel Costs		
Fuel cost rates ($) (at retail rates)	$1.5/L	$0.25/kWh
$ fuel / bus / day	$65 - $85	$22 - $35

The structure of the tariff offered to the bus operator should be carefully considered and will impact not only the economics for the operator but more broadly the impact on the electricity grid. In particular, inclusion of a demand tariff, on the maximum peak demand for the depot over a time period, could potentially blow out costs [6], but may ease potential negative impacts on the distribution grid such as potential exacerbated ramp rates and peak demands. The flexibility of BEB charging

[5] It is important to note that this figure is highly subject to air conditioning rates. Real world testing suggests a fuel intensity of ~1.3kWh/km is realistic, but better data from electric buses in Australian trials should be used to understand the effect of air conditioning.

arrangements suggests, however, that operators may be well placed to obtain competitive retail tariffs.

Grid Augmentation and Infrastructure

If buses are predominately charged at the bus depots rather than along routes, upgrades to the depot substation or grid augmentation may be necessary to support the new load. The cost of grid augmentation represents a principal-agent problem, as the businesses are often liable for the full extent of these costs, but do not own the infrastructure [6]. Appropriate arrangements with the local distribution network service provider (DNSP) will have to be found to equitably allocate costs and benefits.

Bus operators and/or networks should consider behind-the-meter approaches to avoid network augmentation, including pairing BEBs with solar PV and/or stationary battery systems. This will be discussed more in the response to Q3.

Q2 – Energy and Infrastructure Requirements

Question 2: Minimum energy and infrastructure requirements to power electric bus fleets.

Charging Regimes will impact Infrastructure Requirements

As per Table 1, an average bus travelling ~90km/day may consume 90-135 kWh/day, or 33-50MWh/year. The rated range of most BEBs on the market can comfortably support this distance, therefore requiring only 1 charge per day if well managed. This gives flexibility in the types of charging regimes an operator can use:

1. Charging only at the bus depot, typically at the end of the buses' service (overnight)
2. Opportunistically charging during the day, either at the depot, at bus stops along the routes or at the end of the trips (terminals)

Figure 1 gives an overview of the charging regimes that various European BEB projects have used [5]. Different charging hardware is appropriate for the different regimes. For opportunistic charging at bus stops, it is not practical to physically plug in the bus at each stop, so either pantograph charging (overhead or underfoot) or induction charging is necessary, while any of the hardware types shown in Table 2 are appropriate for depot charging.

There is a trade-off between the upfront infrastructure costs of each charging hardware in Table 2 and the upfront costs of the required battery capacity of the bus. If charging infrastructure is only available at the depot, the bus may be required to perform all trips on one charge and should therefore have a larger battery than a bus that can top-up throughout the day at terminals and stops.

Figure 1: European BEB Charging Strategies[6]

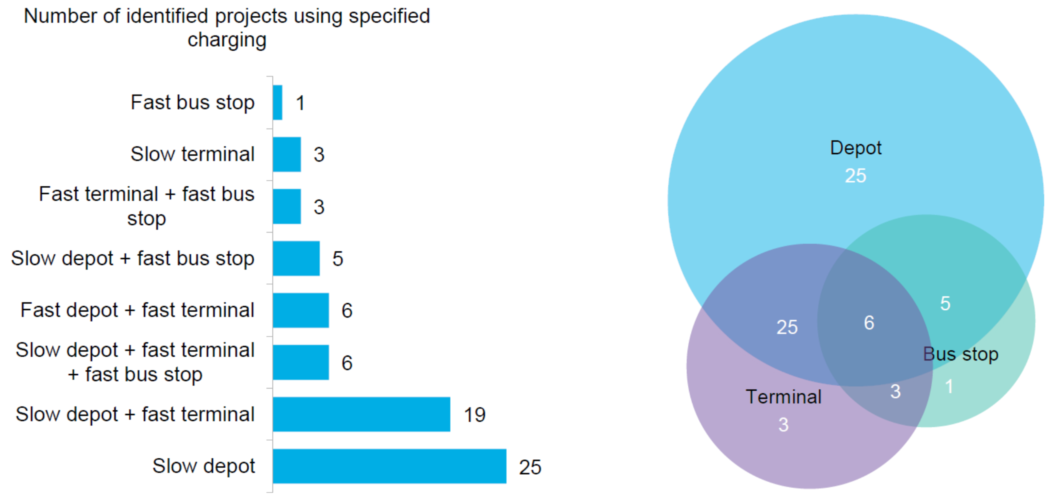


Table 2: Charging Infrastructure

	Plug-In	**Pantograph**	**Induction**
Charging Rates (kW)	Slow: 15-22kW Fast: 22-50kW Rapid: 50-120kW	150-300kW	<200kW
Brands	ABB Toshiba	Proterra Solaris VDL Volvo Van Hool	Not currently commercially mature
Time to fully charge 150kWh[7] battery (hr)	Slow: ~6-10hr Fast: ~3-6hr Rapid: ~1.5-3hr	~0.5-1hr	~1-2hr

Fleet Charging at Depots

Figure 2 shows the maximum coincident demand from BEB charging at the 40 largest depots across NSW if all buses were charged at the same time using 22kW slow chargers. The Ryde depot, with ~320 buses[8], could add an additional 7MW of load at the LV/MV distribution network substation if charged in this manner. If the bulk of charging is scheduled once the buses return to the depot at the end of the day, this may add to peak demand at the network zone substations and exacerbate ramping issues.

Of course, it is highly unlikely that all buses will be charged at the same time. Figure 3 gives an indication of distribution of bus trips throughout across the various bus agencies operating in NSW. Most agencies see a spike in trips occurring at 8am and 3-4pm, with a notable drop in trips during daylight hours. Incentive designs for tariffs for

[6] Figure from [5]

[7] Note that bus battery sizes can range significantly, from 100kWh to 400kWh.

[8] Quantity of buses across depots and agencies from http://fleetlists.busaustralia.com/sta.php?flsummary=STA&ltype=livery

bus operators as well as the scheduling methods need to be carefully designed to shift charging load away from periods of peak demand to low demand periods such as the day (particularly as PV penetrations continue to grow), or overnight.

Figure 2: Maximum Coincident Demand (MW) at Bus Depots - Slow, depot charging (20kW)

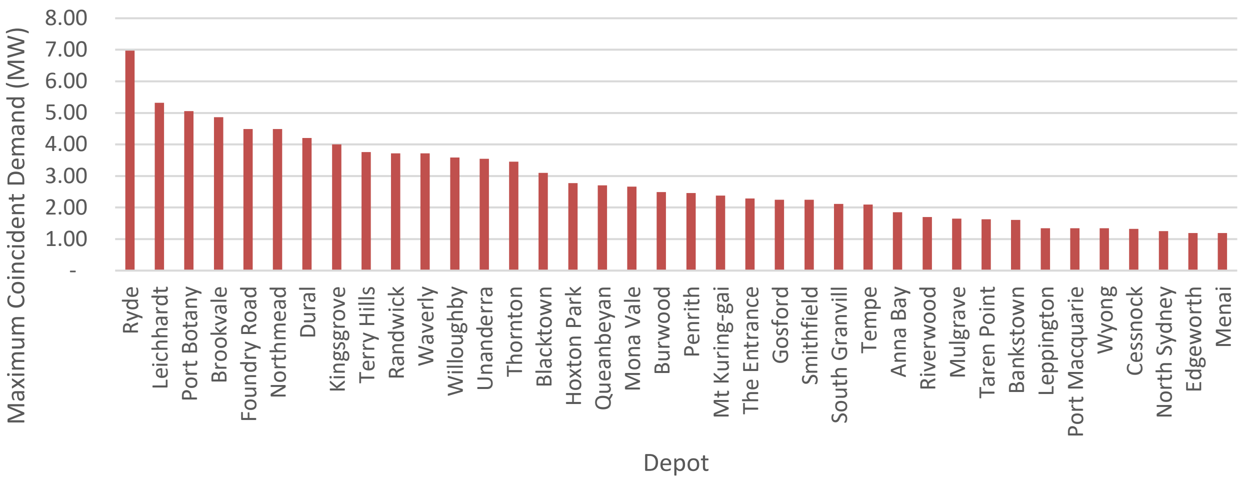
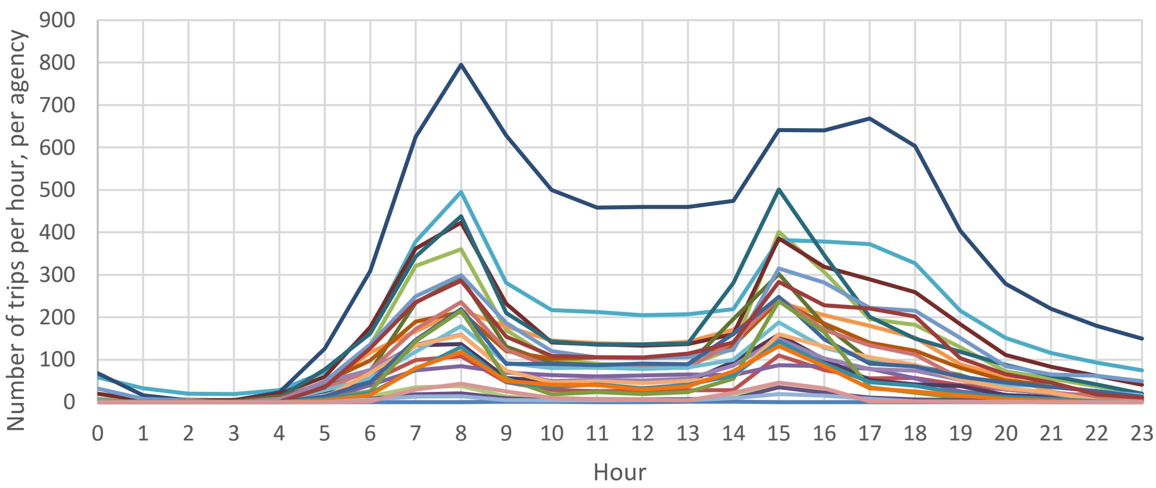


Figure 3: Number of trips per hour for various NSW bus agencies

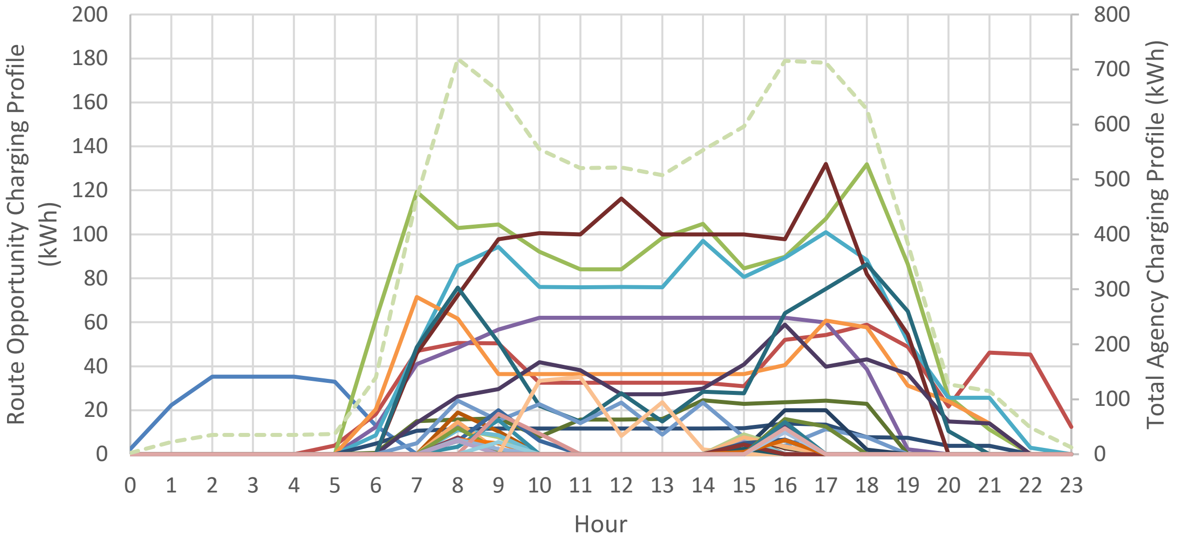


Opportunity Charging at End of Trips

Charging at the end of each trip at the terminal may exacerbate the evening network peak demand as it follows the transport demand. Figure 4 shows the charging profiles of individual routes throughout the day in one Sydney bus agency as well as the total agency profile (dotted). For this agency, a large about of daily charging occurs during 4-7pm, aligning with the peak demand. Opportunity charging could, however, be useful for daytime charging when both demand and typical wholesale electricity prices are low.

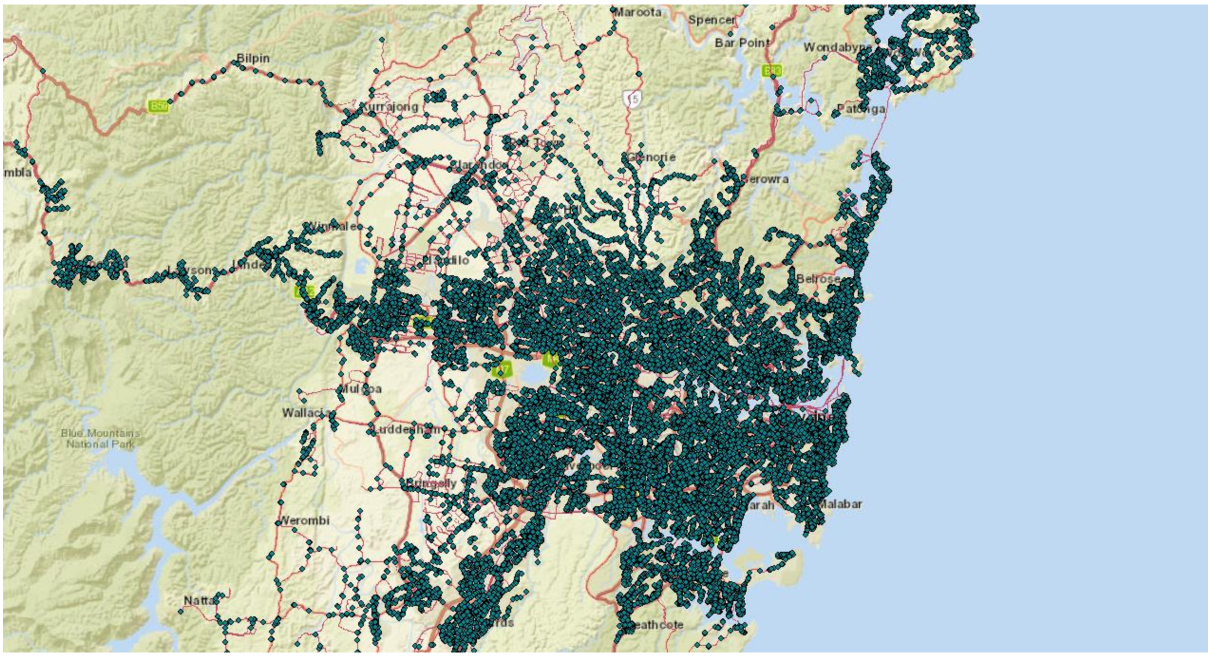
Figure 4: Opportunity Charging at End of Trips – Electricity Consumption Profile (20kW)[9]

[9] N.B. Dotted line is the total agency profile and is on the right axis



This charging regime may also better spatially distribute the load throughout the network as in Figure 5. Distributing the charging infrastructure will require more detailed consideration around which party should pay for the infrastructure, who owns and manages it, and interoperability between different agencies and bus technologies.

Figure 5: Bus stops in the Greater Sydney Region



Q3 – Energy Sources

Question 3: Other renewable, emissions neutral energy sources

The environmental benefit of BEBs as shown in Table 1 will only increase overtime as more renewable energy generators are introduced into the electricity grid. A quicker decarbonisation route is on-site renewable energy generation in the form of solar PV on bus depots, or even integrated with the roof of the vehicle. On-site PV generation will allow operators to benefit from decreased fuel (electricity) costs and if combined with stationary battery storage has the potential manage peak demand to avoid grid augmentation. Off-site renewable PPA arrangements are also an increasingly attractive option, as seen with their use in some other NSW public transport developments.

Solar on Bus Depots and Battery Storage

Buses tend to have a lull in trips during sunshine hours on weekdays, as shown in Figure 3. This provides an opportune time for topping up the fleet directly consuming the electricity generated from on-site PV, ready for the late afternoon/early evening bus trip peak. Crudely, shifting half of the total bus charging load to sunshine hours could reduce fuel costs in half if self-consuming, and further reduce carbon emissions.

Adding stationary battery storage to depots could provide additional opportunity to smooth the electricity demand of the depot as seen by the grid, reducing depot peak demand and any associated demand charges and also potentially deferring any upgrades to the depot transformer and /or grid augmentation required [7].

Solar on Buses

There is current research ongoing around the potential of solar PV integrated into the bus rooftop and or sides. An average bus may have ~30m^2 rooftop space available, currently only being used by HVAC fans. This could fit a maximum potential PV installation of ~2.9kW, generating ~1.3kWh/d, adding ~0.5-2% additional range per day. For a large depot like Ryde, this could offset ~ 150MWh/year, saving ~$38,000/a in fuel costs. [10]

Globally, some trials are active using this technology[11], but it is not yet commercially mature. Future bus procurements should consider integrated PV BEBs as the product matures.

Q6 – Transitioning Metropolitan Fleets

Question 6: Opportunities and challenges of transitioning the entire metropolitan bus fleet to electric

BEB adoption, and adoption of electric vehicles more broadly, is happening during a time of unprecedented change in the electricity sector, with the introduction of distributed energy resources (DERs). It is important to consider BEB adoption in this context, looking past BEBs as a purely a means for transportation, into BEBs as a distributed energy resource. A depot with ~50 buses may effectively wield a battery system in the range of 7.5MWh and a very large depot such as Ryde (~320 buses)

[10] This is the topic of future work by CEEM and supported in part by the Digital Future Grid Institute.

[11] I.e. https://www.prlog.org/12461228-sse-solar-powered-ev-charging-system-applied-into-the-first-solar-powered-bus-in-china.html and http://ceec.uitp.org/photovoltaic-panels-new-warsaw-buses

could have one as large as 50MWh. For perspective, the largest battery installation in Australia, the Hornsdale Power Reserve (aka the Tesla Big Battery), is 129MWh.

We need to carefully consider how we design vehicle charging scheduling to at very least avoid adding additional stress on the grid during network peak times. But we have the opportunity to start to consider the inherent flexibility in the bus fleet that comes with a battery to address other grid issues such as reverse network flows from PV during the day and fast ramping requirements through smart load shifting. Future vehicles may be compatible with vehicle-to-grid (V2G) discharging which will provide greater opportunities for BEBs to be used as a grid-resource and may provide an additional revenue stream for the operator[12].

Q7 – Other

Question 7: Any other related matters.

Credible and accessible data and modelling tools have a key role to play in better understanding BEB opportunities and challenges in the Australian context. Both the transport and electricity sectors are transitioning quickly and are interrelated through electromobility; therefore it is vital that the modelling tools and data are freely available to all and accepted by both sectors.

Models for both the electricity and transport sectors exist. However, they are not currently integrated. As CEEM has previously commented, modelling in the Australian electricity sector has tended to rely on proprietary models from consultancy firms, with limited transparency around assumptions, scenarios and methods [8]. An emerging industry requires clarity and transparency to foster innovation and to remain flexible and therefore we believe the government should require any funded modelling to be open-sourced.

Tools should ideally be constructed in collaboration with experts from both sectors to capture issues, insights and constraints unique to each. Open source tools and data collection will be invaluable to the core stakeholders including:

- *The electricity sector*; to maintain high quality power supply
- *Governments;* to better design informed policy and ensure sufficient transport infrastructure recovery
- *The transport sector;* to better predict and serve consumer's requirements
- *Manufacturing and value chain service industries;* to better innovate and stay competitive internationally

[12] Such as the school bus V2G procurement recently announced by Virginia, USA: https://electrek.co/2019/12/18/daimler-first-winner-in-virginias-massive-v2g-electric-school-bus-procurement/?fbclid=IwAR1BWOrH_JFfe0dTObFnf5QtYZXw47y8hnHrS5TDM2YW9Yd2EntOImNWfNQ

References

1. (ABS), A.B.o.S., *9309.0 - Motor Vehicle Census, Australia, 31 Jan 2019*. 2019: Canberra.
2. (ABS), A.B.o.S., *9208.0 - Survey of Motor Vehicle Use, Australia, 12 months ended 30 June 2018*. 2019: Canberra.
3. Commonwealth of Australia, *State and Territory Greenhouse Gas Inventories 2017*, in *Australia's National Greenhouse Accounts*. 2019.
4. DOEE, *National Greenhouse Accounts Factors*. 2018.
5. BNEF, *Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2*. 2018, Bloomberg New Energy Finance.
6. Gallo, J.-B., *Electric Truck & Bus Grid Integration, Opportunities, Challenges & Recommendations*, in *EVS29 Symposium*. 2016, World Electric Vehicle Journal Montréal, Québec, Canada.
7. Ding, H., Z. Hu, and Y. Song, *Value of the energy storage system in an electric bus fast charging station.* Applied Energy, 2015. **157**: p. 630-639.
8. MacGill, I., et al., *Submission to the Independent Review into the Future Security of the National Electricity Market*. 2017, CEEM.