Electrified Land Transport and Low Temperature Heating in Australia

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Abstract*—Australia is a global pathfinder in terms of rapid renewable energy deployment. It is on track to reach 50% renewable electricity in 2024 and 100% in 2030 if the current deployment rate is sustained. The electrification of transport and low temperature heating provides a significant potential for large emission reduction in Australia if this change is coupled with the decarbonisation of grid electricity. However, additional electric load will also affect the energy balance as well as the energy system costs, especially in a 100% renewable system in which energy generation relies largely on intermittent and non-dispatchable energy sources. In this paper, we model the electric load profiles from 100% electrified land transport fleet and electrified low temperature heating in Australia under various scenarios. The 77TWh additional electricity demand could be incorporated into a 100% renewable electricity system if the flexibility in the loads is managed wisely. The entire electric load could be supplied by solar photovoltaics and wind, and balanced by off-river pumped hydro energy storage, high voltage transmission and demand management at low costs.

***Keywords*—renewable electricity, electric vehicle, heat pump, solar PV, wind, pumped hydro storage**

I. Introduction

The world's energy systems are experiencing a rapid transformation due to increasing concerns regarding climate change and rapid cost reductions in the renewable energy technologies wind and solar photovoltaics (PV). In 2018, about 143 Gigawatts (GW) of net new wind and PV was deployed, which was more than everything else combined (Fig 1). This transition provides opportunities to reduce the dependency on coal, oil and gas, which together cause around 80% of global greenhouse gas emissions.

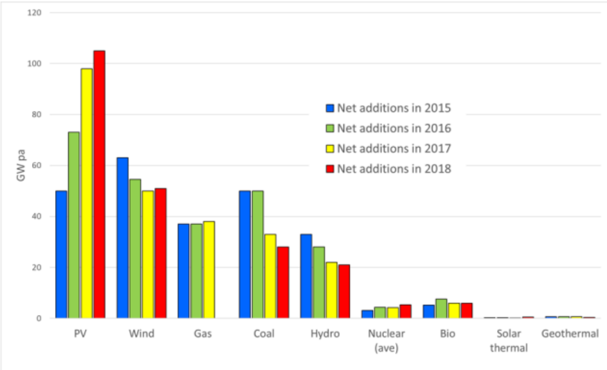

Fig. 1: Global net new generation capacity added in 2015-18 by technology type [1]–[8]

Australia has excellent wind and solar resources. It is installing renewables at a rate of around 250 Watts per person per year (Fig 2), which is 4-5 times faster per capita than the USA, China, EU or Japan and fast enough to reach 50% renewable electricity in 2024 and 100% renewable electricity in 2030 [9]. Grid stabilization with large deployment of PV and wind at modest cost is possible by utilizing existing hydroelectric and bio generation capacity, pumped hydro energy storage (PHES), batteries, high voltage powerlines and demand management [10].

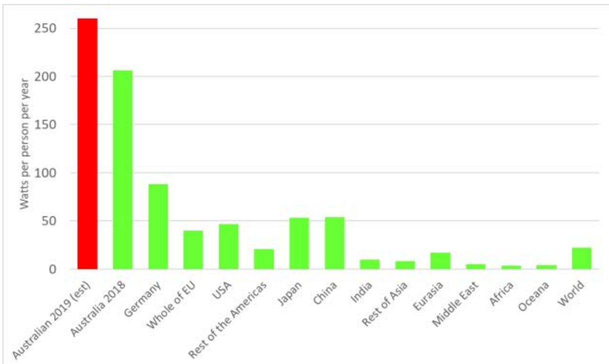

Fig. 2: Annual per capita renewables deployment rate for countries and regions. Data for Australia (2018 and 2019) is from the Clean Energy Regulator [8] and data for other countries/regions (2018) is from IRENA [2].

Emissions from land transport and low temperature heating account for 22% of Australian emissions. The electrification of these two sectors could remove around 122 million tonnes of greenhouse gas emissions if this change is coupled with the decarbonization of grid electricity. Electrification can be achieved by replacing internal combustion engines with electric motors and replacing the current use of gas and liquid petroleum gas (LPG) in space heating, water heating and cooking with cleaner and more efficient electric heat pumps and electric cooking appliances. The electricity demand would increase significantly, but much of this additional electric load would be flexible. Batteries in electric vehicles and hot water tanks allow load shifting or load shedding during critical periods, which would minimize extra utility-scale storage investments utilized for only a few days every few years.

While many studies have investigated the impact of electrified transport on the Australian energy system [11]–[14], few have modelled an entirely electrified fleet powered by 100% renewable electricity, which would result in higher electricity demand, higher flexibility in the load, and higher potential for emission reduction. Also, to the best knowledge of the authors, there is currently no study attempting to model a high resolution (hourly or half-hourly) electrified low temperature heating profile. In response to the deficiencies in the literatures, in this study we aim at investigating the impact of the electrification of land transport and low temperature heating on a 100% renewable electricity system in Australia by modelling the load profile of the additional electricity demand on a half-hourly basis. This paper is structured as follows: Section 2 introduces the methodologies used in this study; Section 3 summaries the modelling results, followed by a discussion of the findings and limitations in Section 4 and the Conclusion section.

II. METHODOLOGY

A. Electrification of land transport

We use historical travelling patterns collected from [15]–[18] to model the charging behaviors of electrified fleet. All modes of land transport including motorcycles, passenger vehicles, light commercial vehicles, articulated trucks, rigid trucks, non-freight carrying trucks, rail and buses are included. The electricity consumption over one year's period for mode i is calculated by:

$$E_i = c_i \times d_i \times (1 + t_{loss})/\eta + v\_loss \times B_i \times 365 \quad (1)$$

where E_i (in kWh) is the annual electricity consumption for mode i, c_i (in kWh/km) is the unit energy consumption for mode i, d_i (in km) is the annual travelling distance for mode i, t_{loss} is the transmission loss, η is the charging efficiency, v_loss is the additional loss due to the energy used to power on-board electronics and B_i is the nominal battery capacity for mode i.

The annual electricity consumption E_i is then distributed over the year in different ways depending on the charging regime, including:

- End-of-trip charging: drivers park and plug in and start charging immediately after travel
- End-of-day charging: all vehicles are plugged in as drivers arrived home, during the period 4-7 pm, and start charging with no control
- Night time charging: charging overnight to fill evening valleys in baseline demand
- Daytime charging: charging during the day to take advantage of PV availability

The night and daytime charging regimes are assumed to be utility controlled: a central agent will manage the state of charge of the vehicles and manage the charging across the network to best match the target profile.

Considering that the utilisation rates are currently much higher for non-passenger vehicles, and so charging profiles for these classes of vehicle will be less flexible. Therefore, only passenger vehicle charging regimes are varied in this study.

B. Electrification of space heating

We apply the concept of Heating Degree Days (HDD) and assume that the unadjusted space heating requirement (D_t) at each timestep (half-hour) is proportional (constant k) to the difference between the ambient temperature (T_i) and the base heating temperature (T_{base}) if $T_i < T_{base}$, otherwise D_t is zero. The sum of D_t over a year need to be consistent with the annual heating requirement (D_{annual}) calculated from gas and LPG usage data collected from [19], [20]. D_t is then converted to the electric load (E_t) by taking into account the coefficient of performance (COP_t) of electric heat pumps and the occupancy (O_t) of the buildings. This methodology is shown in Equation 2-4.

$$D_{annual} = \sum_{t=1}^{17520} D_t \quad (2)$$

$$D_t = k \times (T_{base} - T_i) \; if \; T_i < T_{base} \; else \; 0 \quad (3)$$

$$E_t = D_t \times O_t \,/\, COP_t \quad (4)$$

To determine the base heating temperature we plot the historical daily electricity consumption data (from [21]) against daily temperature data (from [22]) over the same period for each climate zone defined by the Australian Building Codes Board [23]. We then fit the data with piecewise regression with 2 breakpoints, assuming that there are three segments: a negative correlation indicating space heating in winter, a flat line indicating no heating or cooling loads, and a positive correlation indicating space cooling in summer. The heating base temperature is therefore the temperature value of the first breakpoint. A sample plot for Climate zone 7 using the net system load profile of ActewAGL is shown in Fig 3.

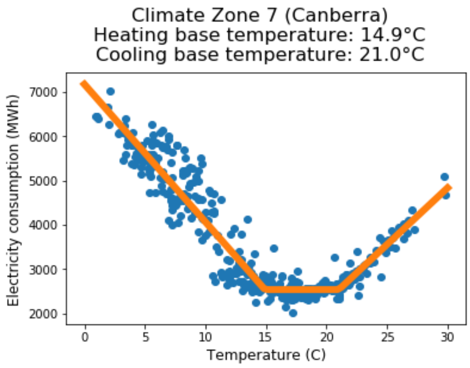

Fig. 3: Plot of daily electricity demand against daily average temperature for Canberra, Australia. The entire Canberra is in Climate zone 7. ActewAGL is Canberra's leading electricity and gas provider [24]. Its network covers whole of Canberra and surrounding New South Wales region, therefore its net system load profile is a good representation of the Canberra's electricity demand. 2017 data is used for the plot.

C. *Electrification of water heating and cooking*

The methodologies used to model electrified water heating and electrified cooking are similar. The annual heat demand calculated from the data in [19], [20] is distributed throughout the year following certain usage patterns. The daily hot water use patterns are from [25], [26] with seasonal adjustments defined in [25] applied. The cooking energy use patterns are simulated based on the restaurant occupancy profiles specified in [27] and is assumed to be temperature independent. The methodologies described above are expressed in Equation 5 and 6.

$$D_{water,annual} = \sum_{m=1}^{12} \sum_{t=1}^{n} k_{water} \times d_t \times s_m \tag{5}$$

$$D_{cooking,annual} = \sum_{t=1}^{17520} k_{cooking} \times d_t \tag{6}$$

where D_{annual} is the annual heating demand; d_t is the normalized usage at time t (half-hourly) so that the sum of d_t over one day equals 1; k is a constant value used to unify the normalized values with the real heating demand, n is the number of half-hour intervals in month m, and s_m is the seasonal scaling factor ranging from 0.7 in July (winter) to 1 in December to March (summer).

Unlike the load from space heating and cooking which is instantaneous, water heating load can be shifted by pre-heating the water in hot water tanks, allowing flexibility in the load. Therefore, we have also modelled daytime and night time scenarios for water heating, in the same way we model utility controlled electric vehicle charging.

III. RESULTS AND DISCUSSION

Our modelling suggests that an average of 77 Terawatt hours (TWh) additional electric load is added by the electrified fleet per annum, which is around 38% of the baseline electric load (205 TWh per year). Much of the additional load is from passenger vehicles (34 TWh or 17% of the base load). A breakdown by mode is shown in Fig 4.

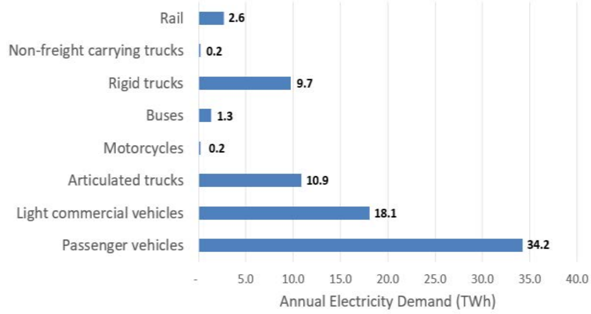

Fig. 4: Additional electric load added by each mode of transport. Passenger vehicles account for 45% of the total.

Additional electric load from electrified low temperature heating, however, represents a smaller faction, mainly due to the high coefficient of performance of heat pumps (200%-400%). Space heating, water heating and cooking would increase the electricity demand by 3%, 3%, and 2% respectively.

The modelled electric load profiles for the unregulated scenario (end-of-trip charging for electric vehicles), combined daytime scenario and combined night time scenario over several days in July 2010 are shown in Fig 5-7 respectively.

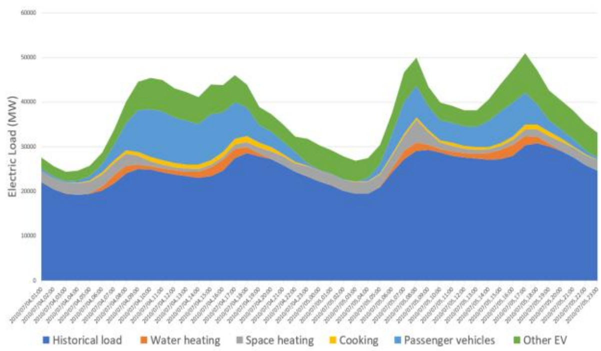

Fig. 5: Electric load profiles for the unregulated scenario for a weekend (left) and a weekday (right) in July 2010.

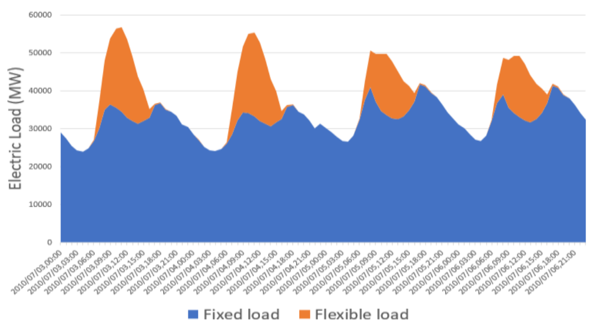

Fig. 6: Electric load profiles for the daytime scenario for 4 consecutive days in July 2010. "Flexible load" includes the charging load of passenger vehicles and the water heating load. "Fixed load" includes all other components.

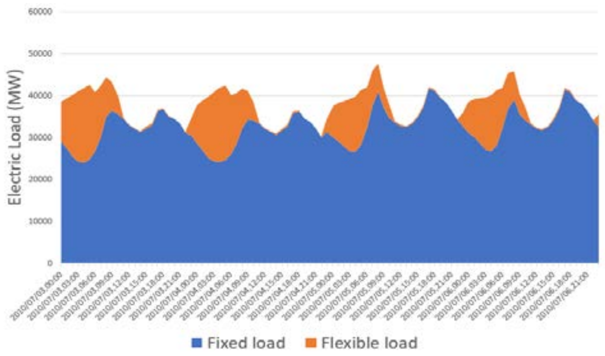

Fig. 7: Electric load profiles for the night time scenario for 4 consecutive days in July 2010. "Flexible load" includes the charging load of passenger vehicles and the water heating load. "Fixed load" includes all other components.

IV. DISCUSSION

In this study we model the load profiles from the electrification of land transport and low temperature heating in Australia. Our earlier work models the Australian National Electricity Market in a 100% renewable scenario, with wind and solar PV providing over 90% of the electricity demand and off-river PHES together with interstate high voltage transmission balancing the supply and demand on an hourly basis [28]. The levelized cost of electricity (LCOE) is around $AUD75/MWh, which is below the cost of electricity from existing gas-fired power stations and is also below the cost of new-build gas and coal power stations.

Electrification of land transport and low temperature heating would increase the electricity demand by about 50%. All of this additional demand could be provided by solar PV and wind and supported by off-river PHES and HVDC/HVAC.

While the annual electricity demand increases by around 50%, the peak demand nearly doubles for the unregulated scenario, especially on weekdays (right). This is expected, as the time that commuters arrive at workplace and home coincides with morning and evening peaks. In a 100% renewable electricity system this would result in a significant increase in the required storage, especially the power component. Space heating load is high during nights and early mornings when the temperature is low and the occupancy of residential buildings is high. Space heating load in commercial buildings is significantly lower than that in residential buildings.

Flexible load includes the charging load of passenger vehicles and water heating load, representing around 15% of the combined electricity demand. Daytime scenario introduces a significant peak at noon. However, it is unlikely that this would result in a significant increase in the required storage capacity, as in Australia the power output from solar PV and wind over the shoulder periods is consistently high, primarily due to the excellent solar and wind resources, the large network area and the strong interconnection that smooths out local weather effects.

Moving the flexible loads to the evening valleys in the baseline demand would also result in a slight increase in the peak load. However, the peak time is shifted from 5-7pm to around 9am in the morning. This would result in a slight increase in the required storage capacity to store the excess electricity generated in the previous day. The energy spillage is also likely to increase.

The combined profile is largely determined by the way the electric vehicle charging load is incorporated into the system. The impact from low temperature heating is minimal, despite that hot water tanks provide opportunities for load shifting during critical periods.

A preliminary energy balance analysis has found that when only the electrified land transport is included, the LCOE would increase to AUD$81/MWh for the end-of-trip scenario, and to AUD$78/MWh for the daytime charging scenario. The cost of electricity is always higher than the scenario without electric vehicles due to the limited availability of dispatchable existing hydro and biomass. Their scale is diluted in a larger generation mix. However, the increase in LCOE is small (only 4-8%) except for the end-of-day scenario. This suggests that the electrified fleet could be easily incorporated as long as the charging behaviour is not extreme. Further analysis will perform a complete energy balance analysis with electrified low temperature heating included as well, while it is expected that its impact on LCOE is neglectable.

V. CONCLUSION

Australia is installing solar PV and wind at a rate of 6 GW per annum and is on track to achieve 100% renewable electricity by 2030 if this deployment rate is sustained. Electrification of land transport and low temperature heating is Australia could remove nearly a quarter of Australia's emissions if this change is coupled with the decarbonization of grid electricity. In this study we model the half-hourly electric load profiles of the electrified land transport fleet and electrified low temperature heating. We find that the electricity demand would increase by 50%, and the peak load would double if the electricity usage is unregulated. Nearly half of the additional load is flexible, allowing load shifting or load shedding during critical periods. The additional electricity demand could be incorporated into a 100% renewable electricity system mostly supplied by solar PV and wind and balanced by off-river PHES and high voltage transmission at low costs while significantly reducing emissions.

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