Centre for Energy and Environmental Markets

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Data-driven assessment of distributed PV systems and their impacts on electricity network planning and operation

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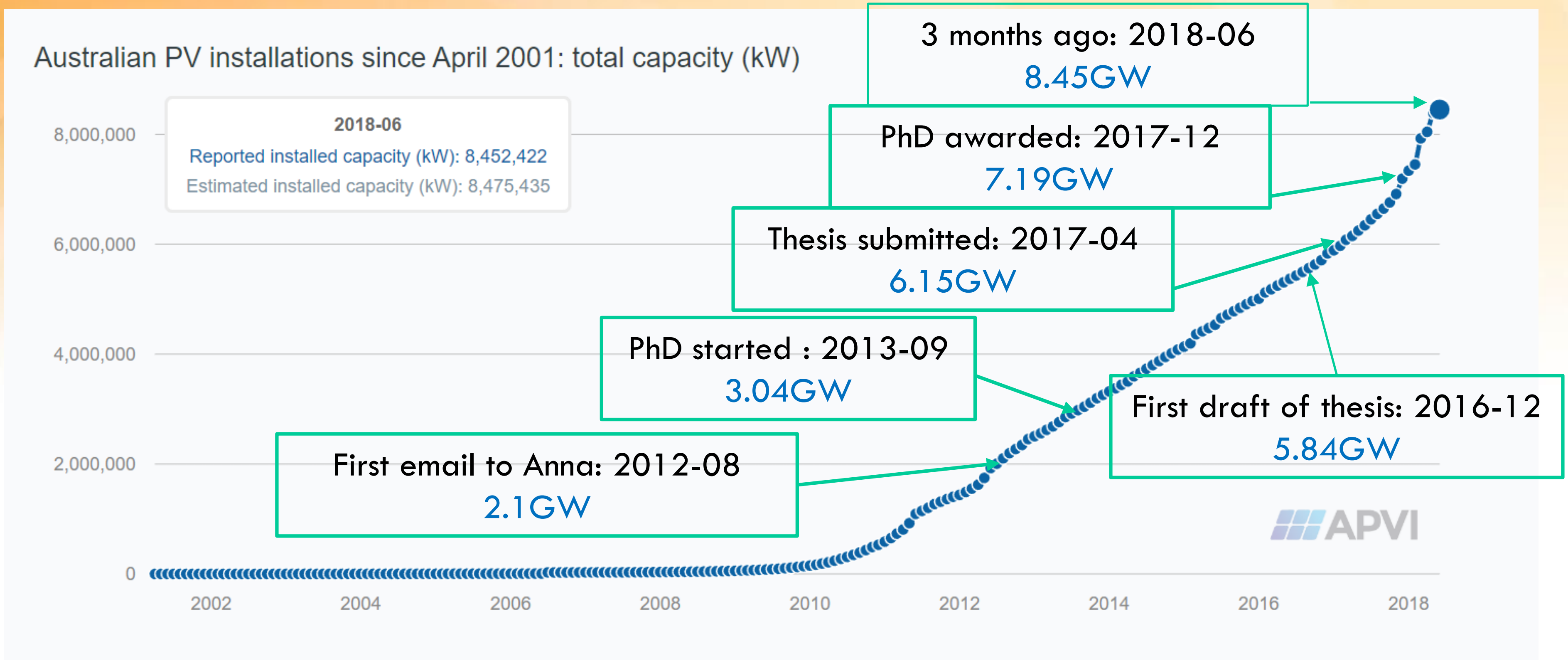
UNSW SPREE Seminar

20 September 2018

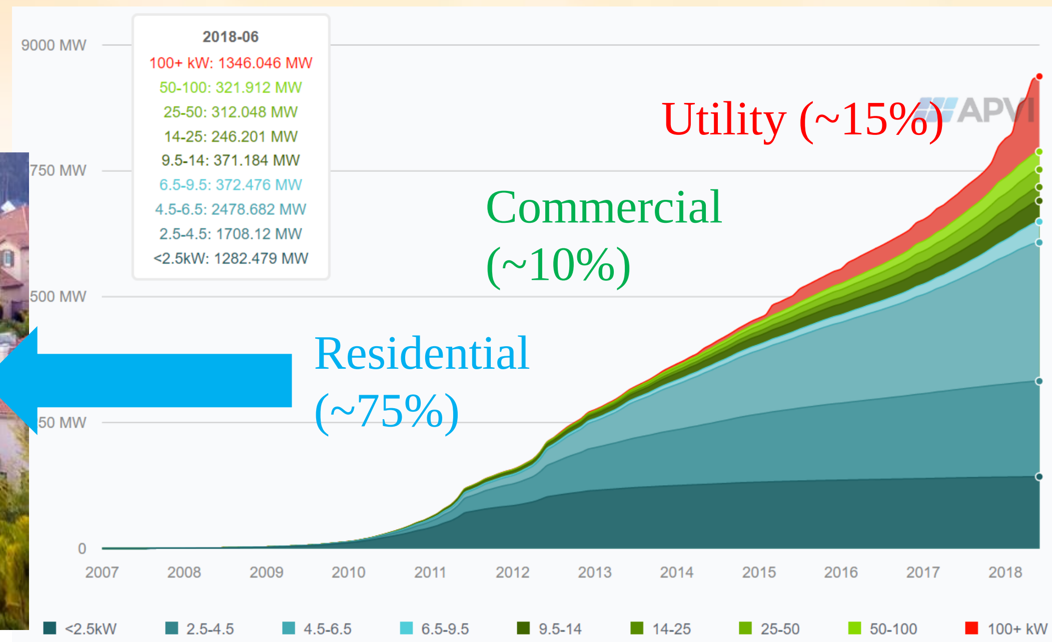
A PhD story with lots of fun!



Australia: World's highest residential PV penetration (21% of suitable dwellings)
5th in terms of per-capita PV capacity

Context:

- Numerous small scale PV systems exist in the network with very limited monitoring/control
- Good estimates of the operational performance and impact of distributed PV is needed

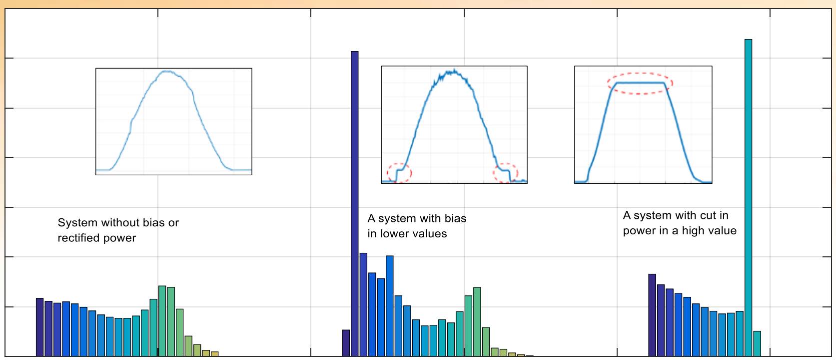


Steps of the PhD:

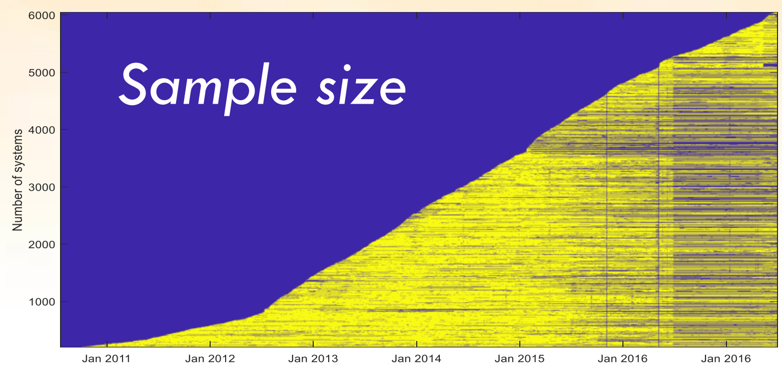
- Provide and test a set of techniques to improve the quality of data and metadata from distributed PV systems
- To estimate aggregate PV generation including non-monitored system
- And to estimate the potential impacts of these systems on transmission and distribution networks

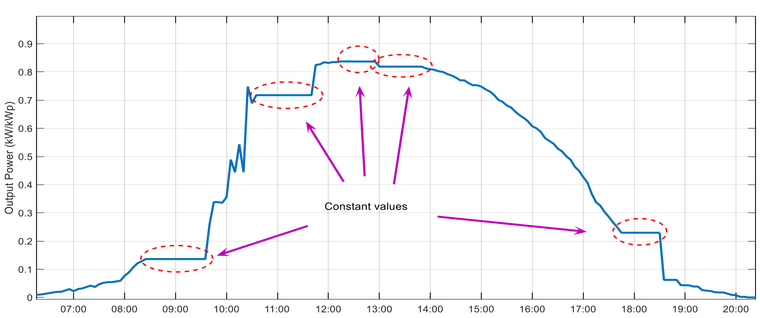
Data and meta-data quality check

- Individual PV system output data from ~5000 distributed PV systems PVOutput.org for +5 years (300,000,000 records)
- A set of filtering methods applied to flag/remove the likely invalid data



Monitoring issue





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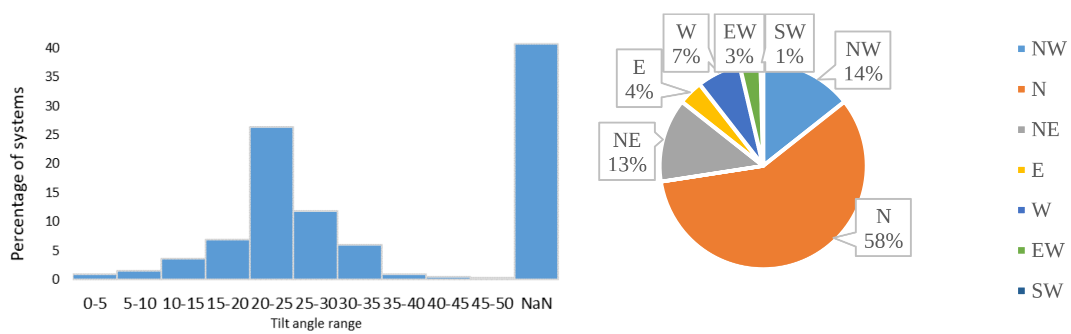
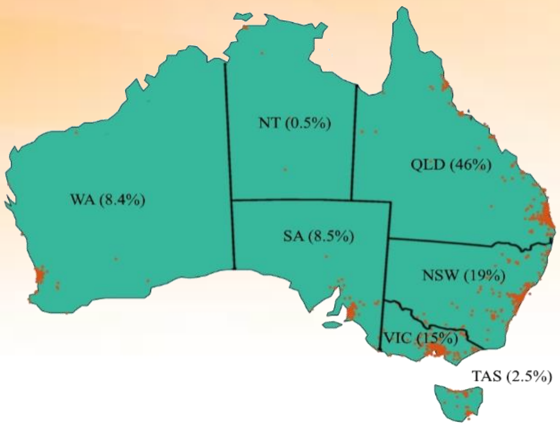
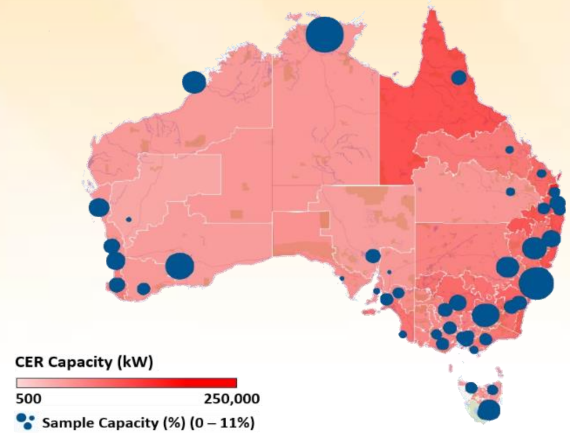


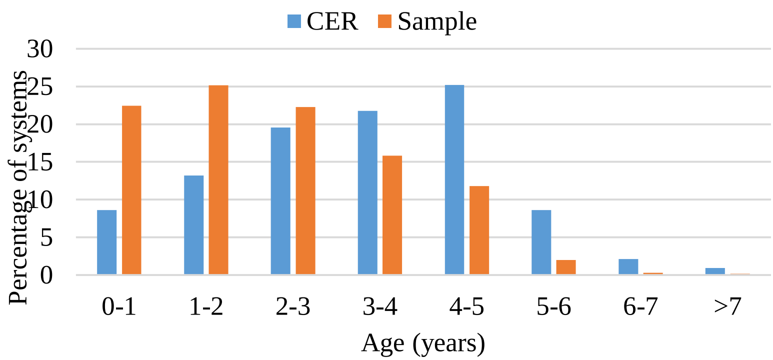
Tilt and orientation of systems

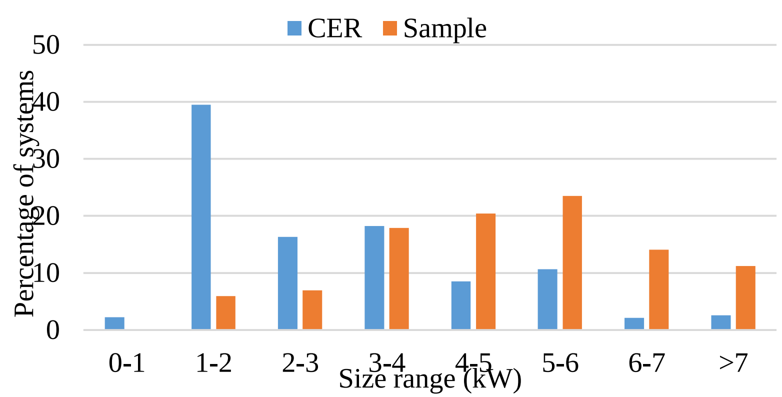
Data and meta-data quality check

- The characteristics of the sample data was compared to all PV systems installed in Australia *(Sourced from Clean Energy Regulator)*









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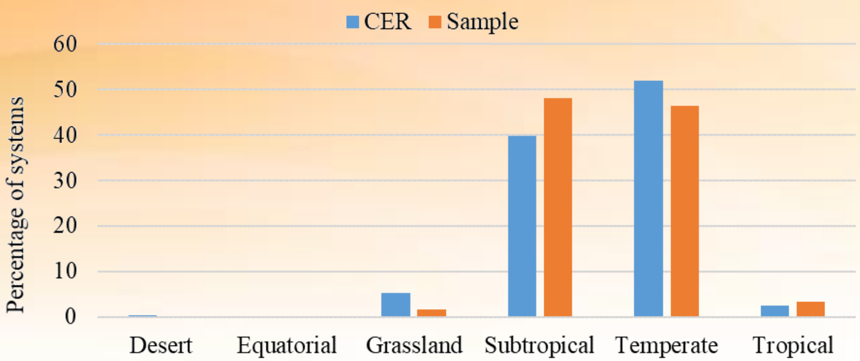
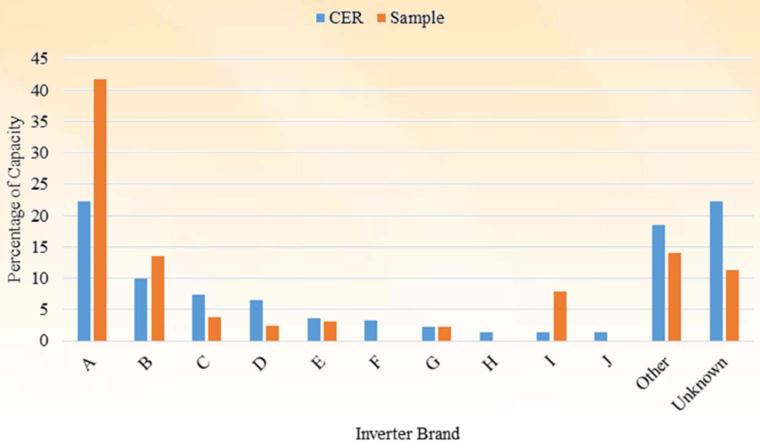
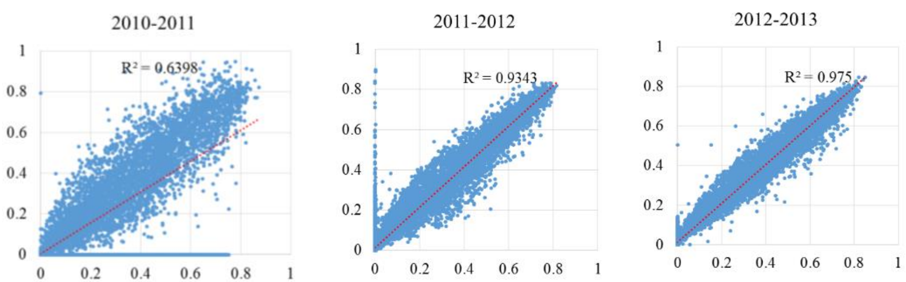
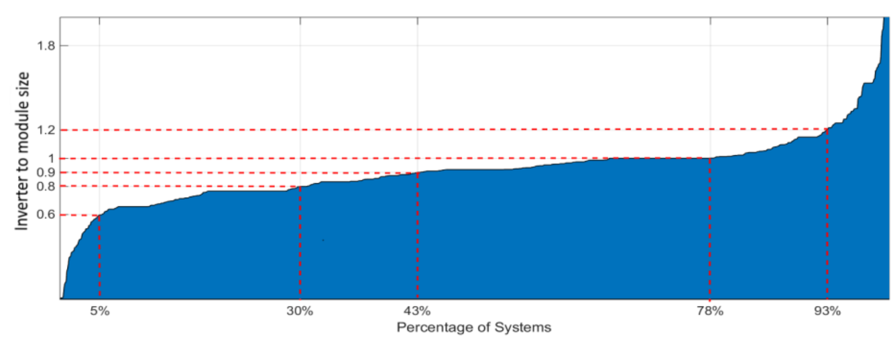




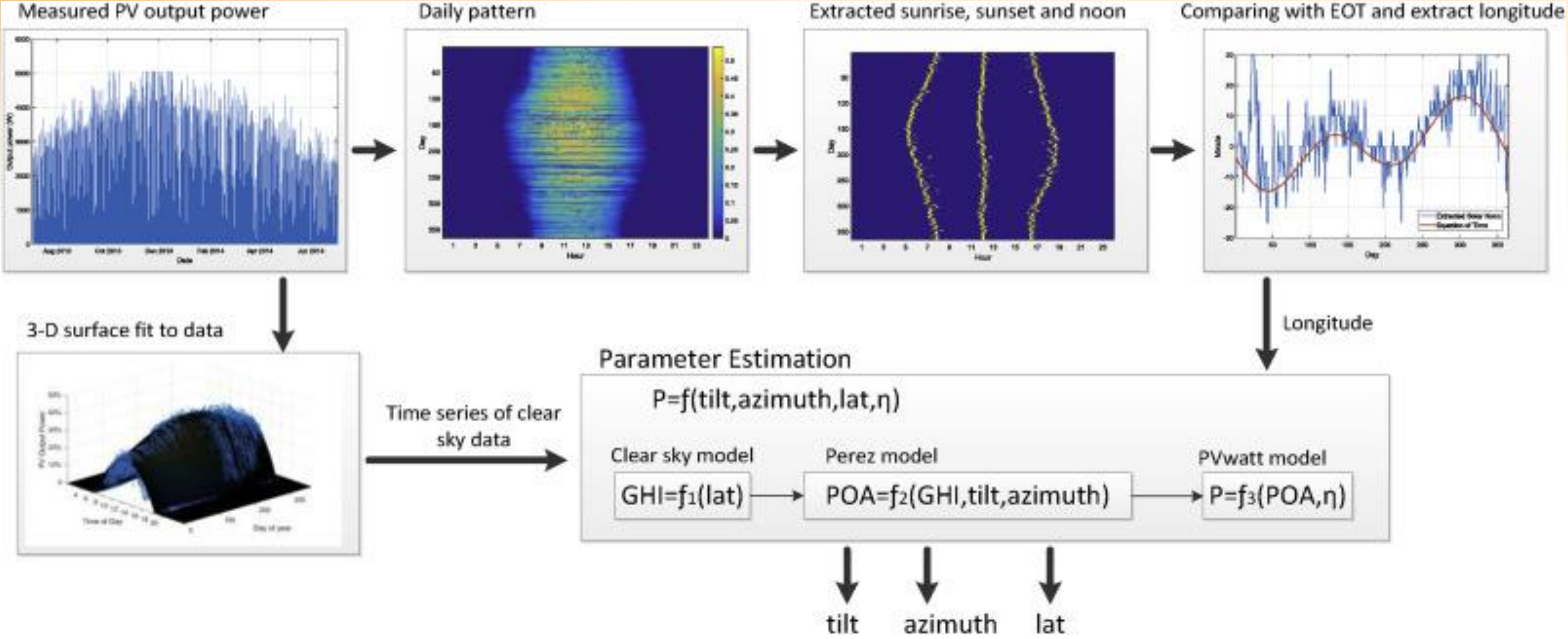


Sample performance (vertical axis) vs. average Ausgrid PV system performance (horizontal axis) for three years for 2-digit postcode 21XX



Estimation of Distributed PV Systems' Installation Parameters

- Self reported meta data (tilt, orientation, and location) are not usually reliable
- Automatic detection of installation parameters can help in quality checking which is necessary for performance analysis

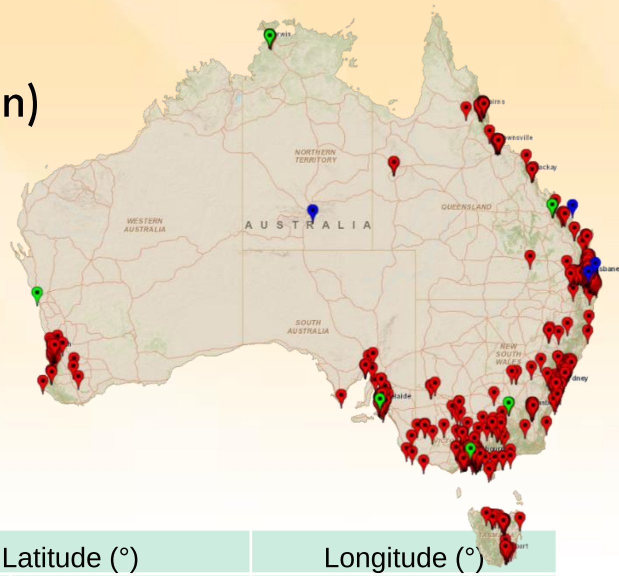


Haghdadi, N., Copper, J., Bruce, A. and MacGill, I., 2017. A method to estimate the location and orientation of distributed photovoltaic systems from their generation output data. Renewable Energy, 108, pp.390-400.

Estimation of Distributed PV Systems' Installation Parameters

Three case studies defined to test the method:

- Simulated PV systems using meteorological data (green)
- PV systems with validated parameters (blue)
- PV systems with self-reported installation parameters (red)

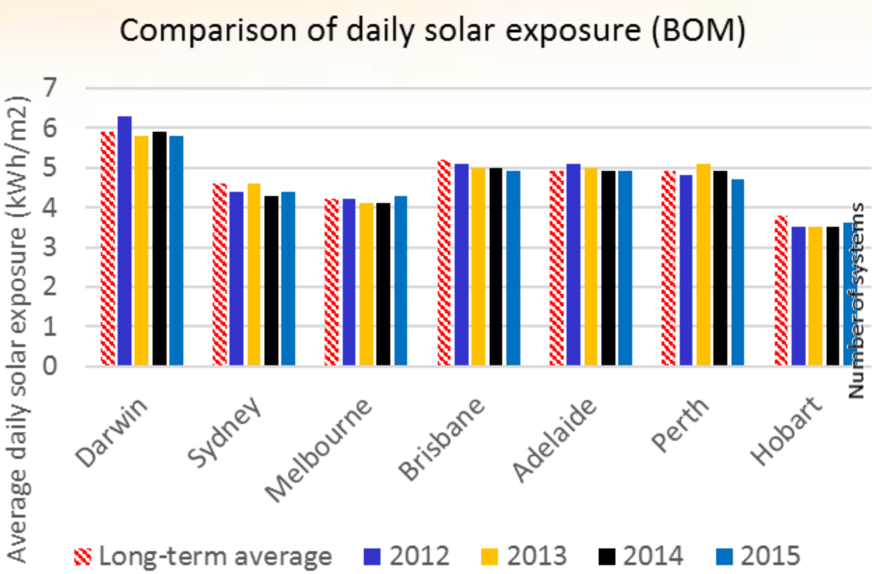


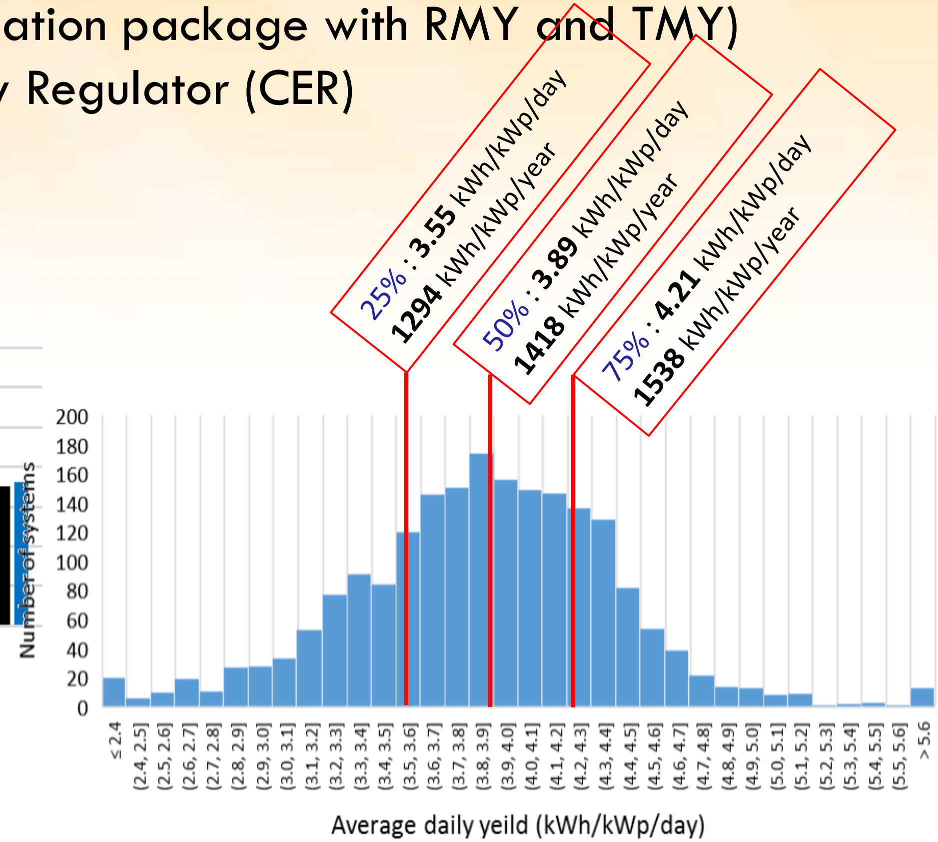
	Tilt (°)			Azimuth (°)			Latitude (°)			Longitude (°)		
	MBD	MAD	STD	MBD	MAD	STD	MBD	MAD	STD	MBD	MAD	STD
Case Study 1-1	-4.47	6.70	11.43	-2.33	10.89	27.12	2.42	4.84	3.42	-0.02	0.23	0.12
Case Study 1-2	-2.12	2.75	2.93	-0.83	5.85	4.07	3.97	4.08	2.12	-0.01	0.20	0.08
Case Study 2-1	-1.13	5.26	4.21	7.80	9.84	6.84	4.44	5.84	3.42	-1.22	1.22	0.78
Case Study 2-2	-4.18	4.18	1.30	-	-	-	4.57	4.57	1.65	-0.52	0.52	0.47
Case Study 3	-0.96	4.18	3.34	3.55	17.63	20.64	1.40	3.75	2.94	-0.69	1.18	1.40

Haghdadi, N., Copper, J., Bruce, A. and MacGill, I., 2017. A method to estimate the location and orientation of distributed photovoltaic systems from their generation output data. Renewable Energy, 108, pp.390-400.

Operational Performance Analysis of Distributed PV Systems

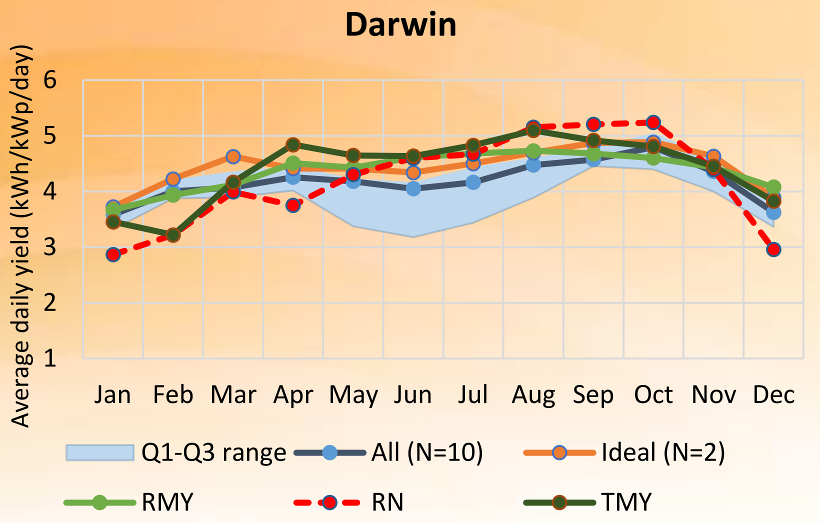
- The real performance of distributed PV systems is analysed and compared with publicly available estimates including:
  - ❖ Renewables.ninja (open-source model using NASA Merra re-analysis data)
  - ❖ PV_Lib (Sandia national lab's simulation package with RMY and TMY)
  - ❖ Average estimates of Clean Energy Regulator (CER)
  - ❖ And Clean Energy Council (CEC)

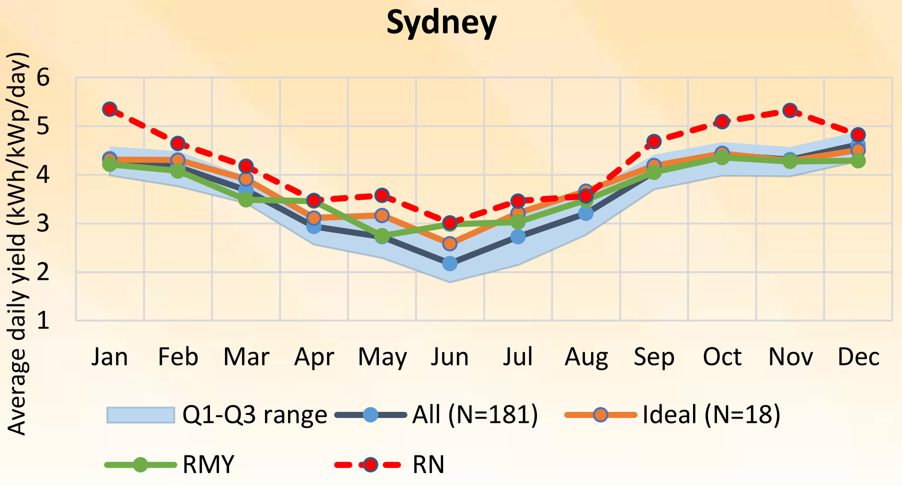


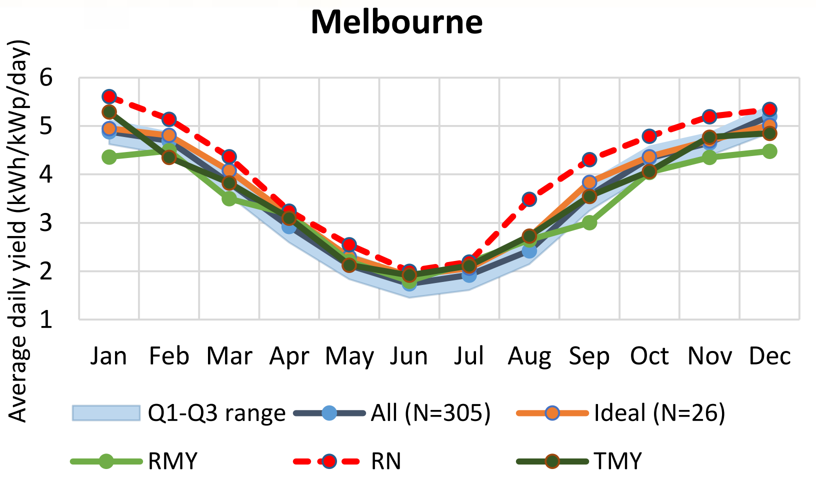


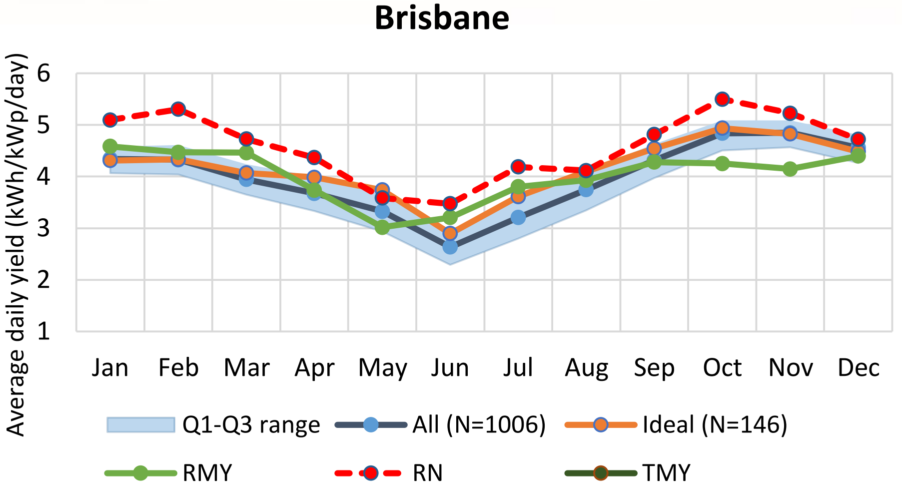
N. Haghdadi, J. Copper, A. Bruce & I. MacGill "Operational performance analysis of distributed PV systems in Australia". Asia-pacific Solar Research Conference, November 2016, Canberra, Australia

Operational Performance Analysis of Distributed PV Systems









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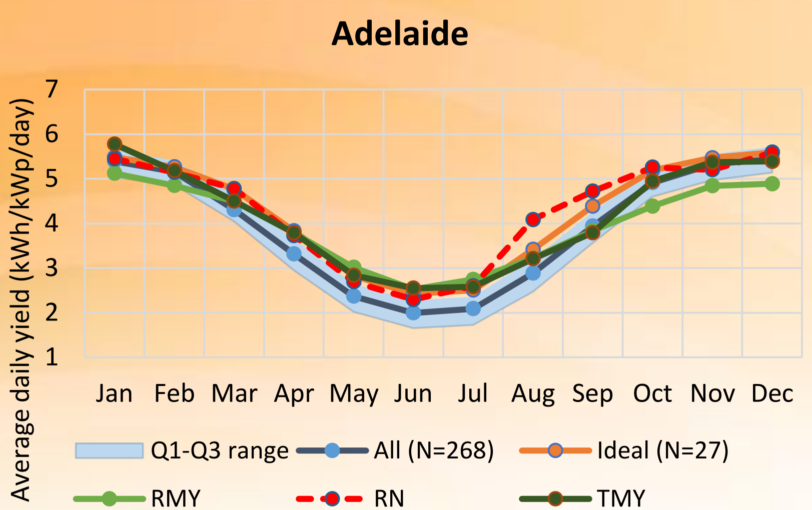
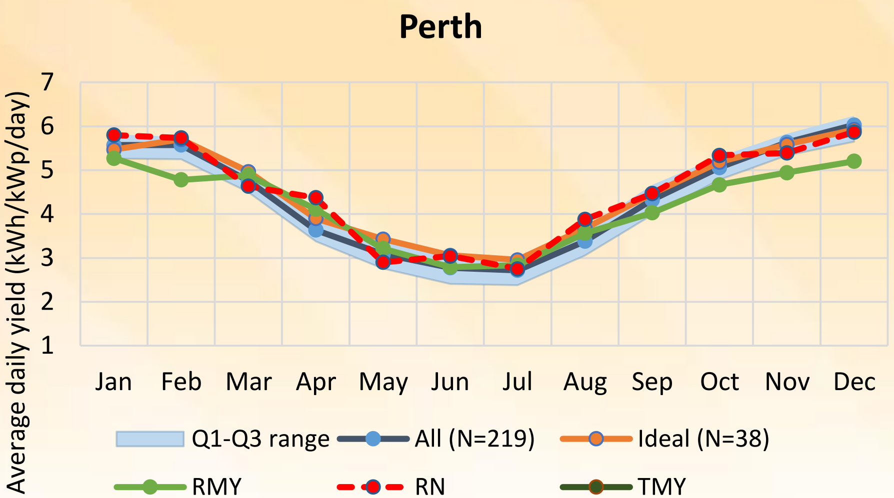
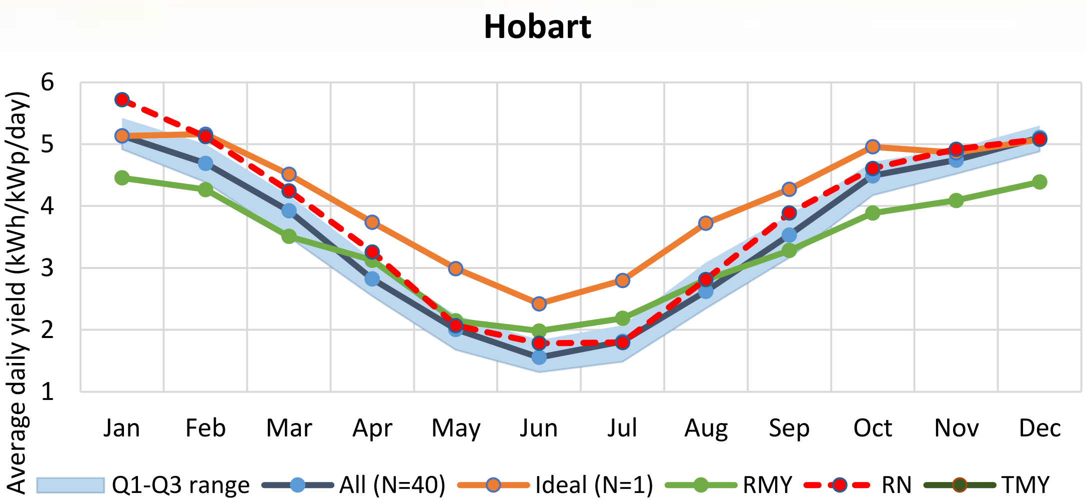
Operational Performance Analysis of Distributed PV Systems







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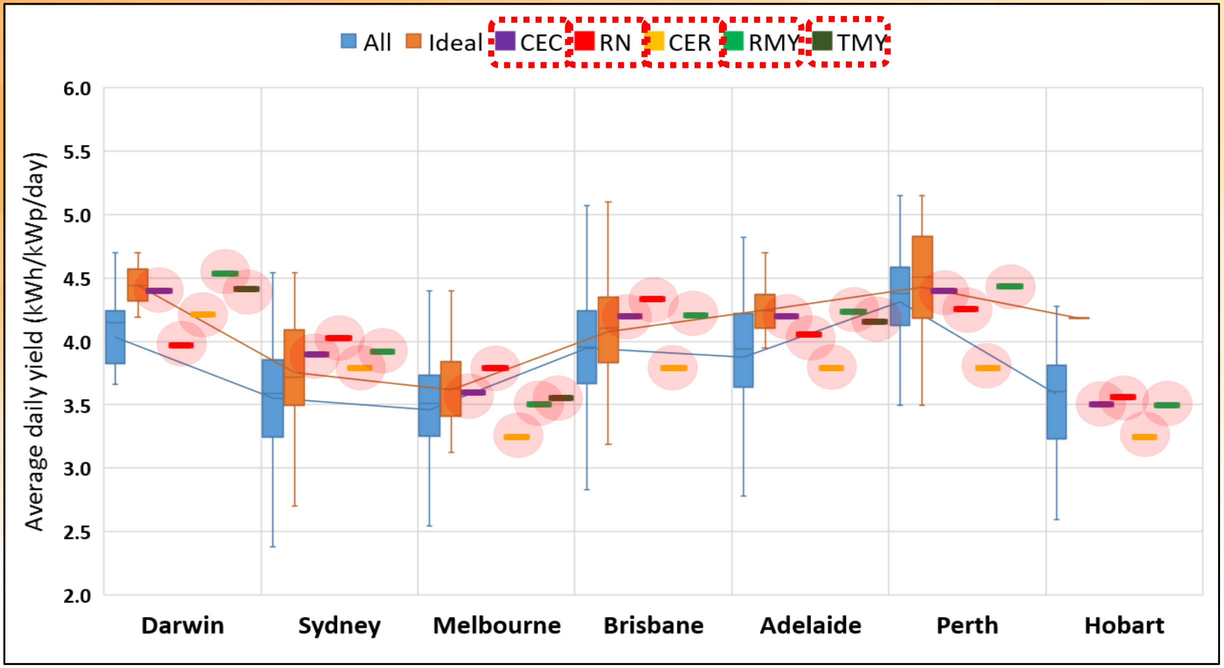
Operational Performance Analysis of Distributed PV Systems



Main takeaways:

- CEC, RMY, and TMY are more aligned with ideal subset
- CER is more aligned with all systems
- RN is generally overestimating the performance

	Average daily yield (kWh/kWp/day)								
City	CEC	RN	CER	RMY	TMY	All	Ideal	N all	N Ideal
Darwin	4.40	3.97	4.21	4.53	4.41	4.15	4.44	10	2 (20%)
Sydney	3.90	4.03	3.79	3.91	-	3.59	3.72	181	18 (10%)
Melbourne	3.60	3.79	3.25	3.50	3.55	3.51	3.62	305	26 (9%)
Brisbane	4.20	4.33	3.79	4.20	-	3.95	4.11	1006	146 (15%)
Adelaide	4.20	4.05	3.79	4.23	4.15	3.94	4.24	268	27 (10%)
Perth	4.40	4.26	3.79	4.43	-	4.38	4.51	219	38 (17%)
Hobart	3.50	3.56	3.25	3.49	-	3.60	4.18	40	1 (3%)
							Sum	2029	258 (13%)

	Bias from the median of ideal subset				
	CEC	RN	CER	RMY	TMY
	-0.9%	-10.7%	-5.3%	2.0%	-0.6%
	4.9%	8.3%	1.8%	5.3%	
	-0.6%	4.6%	-10.4%	-3.3%	-1.9%
	2.3%	5.5%	-7.8%	2.3%	
	-0.9%	-4.4%	-10.7%	-0.1%	-2.0%
	-2.4%	-5.6%	-16.0%	-1.7%	
	-16.3%	-15.0%	-22.4%	-16.5%	
min	-0.6%	-4.4%	1.8%	-0.1%	-0.6%
max	-16.3%	-15.0%	-22.4%	-16.5%	-2.0%
MBD	1.05%	2.76%	-8.94%	1.05%	-1.91%
MAD	2.20%	5.60%	9.19%	2.36%	1.91%

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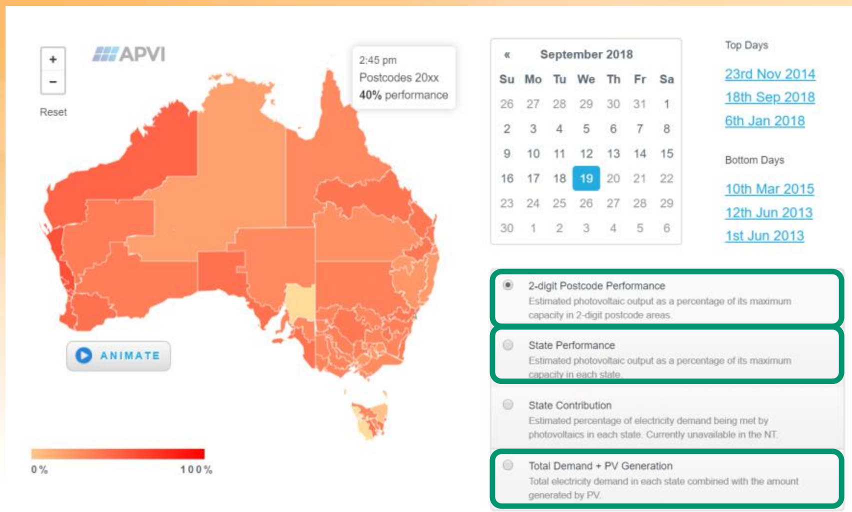
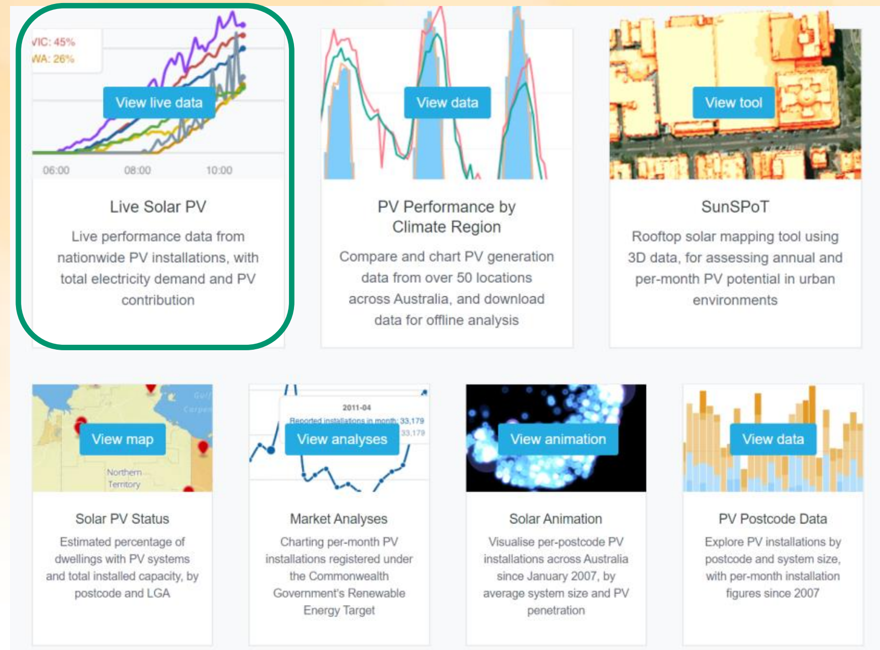
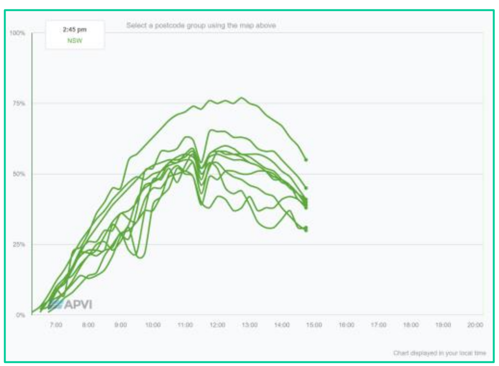
Generation Mapping of Distributed PV Systems

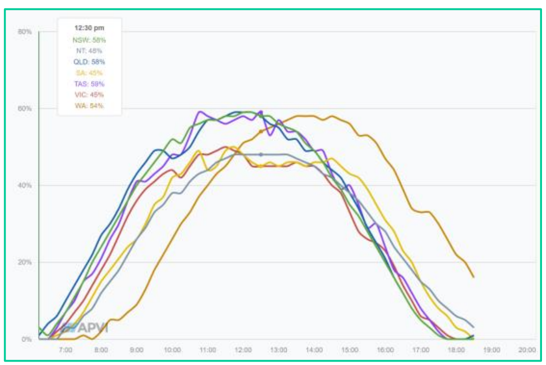
http://pv-map.apvi.org.au/

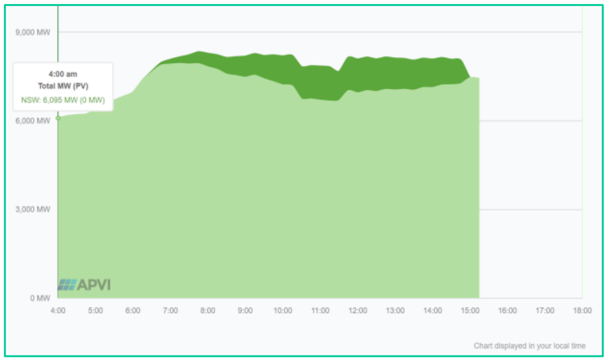
- Live distributed PV systems output data





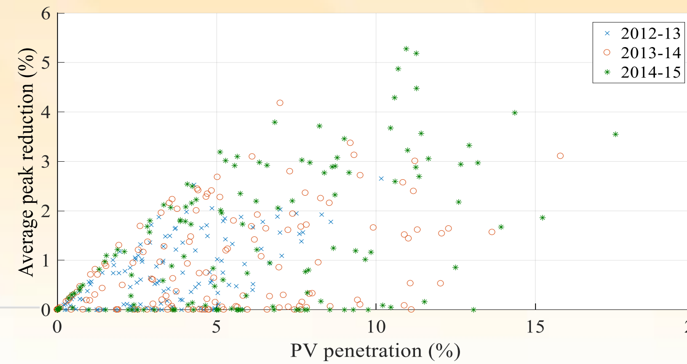




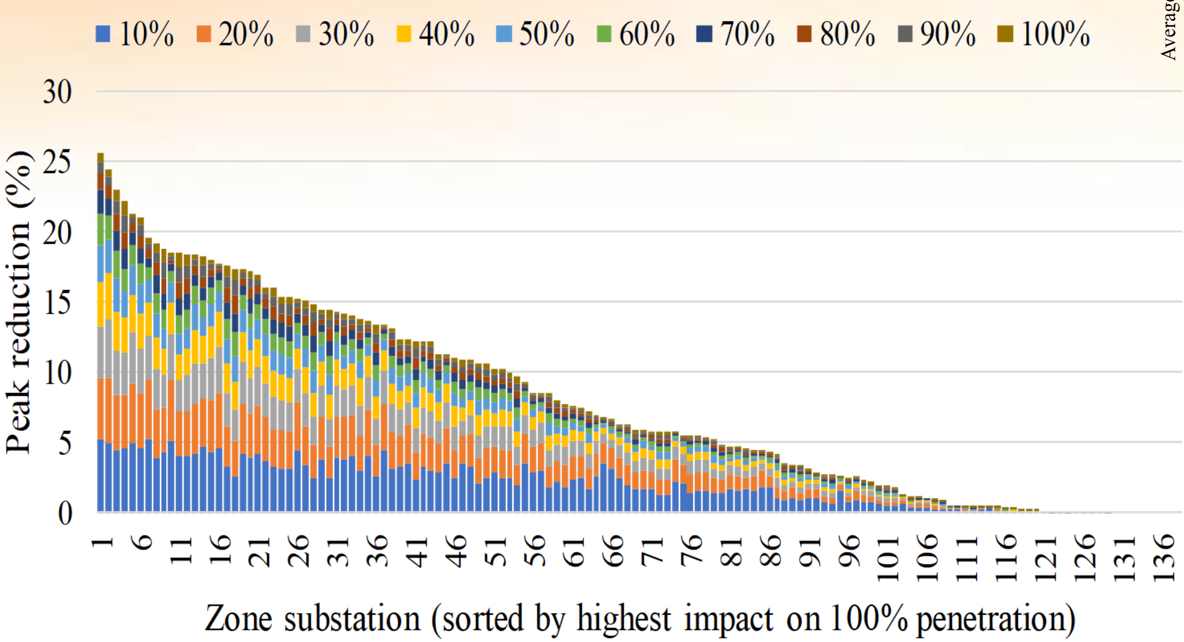


Impact of Distributed PV on Zone Substation Peak Demand

- PV systems performance is upscaled by the capacity of PV installed in each distribution feeder to estimate the contribution and impact of PV

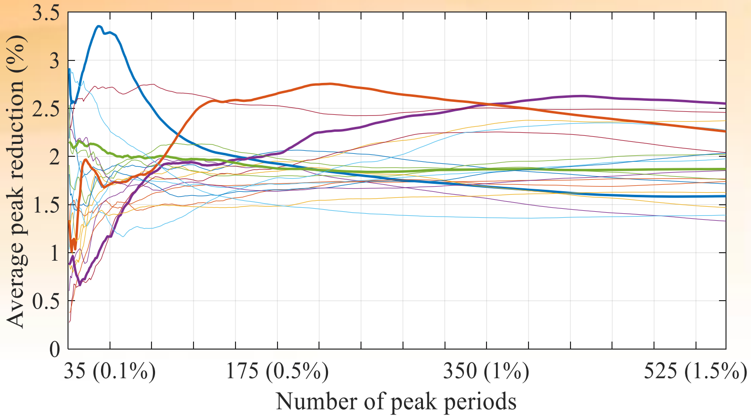


Estimated peak reduction from present PV penetrations for 138 Ausgrid ZS

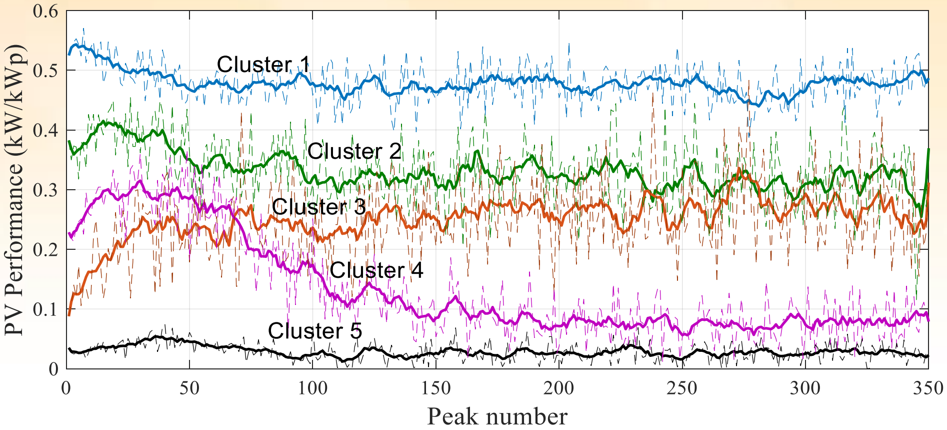


Impact of Distributed PV on Zone Substation Peak Demand

- PV systems performance availability in peak times of the zone substations is clustered



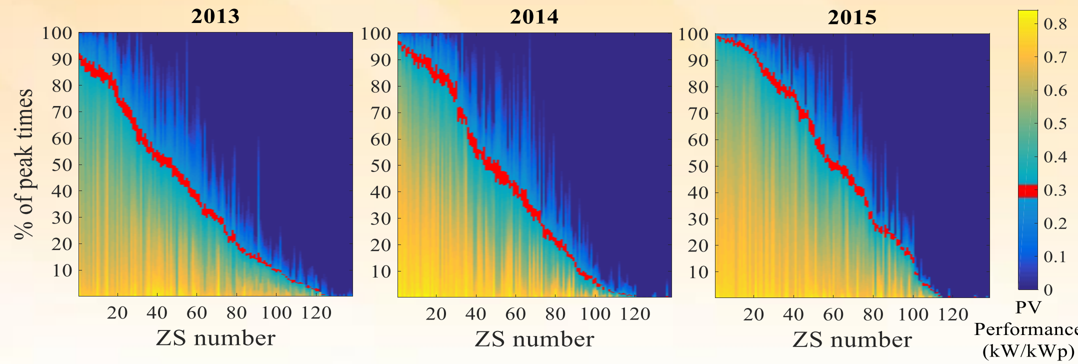
Average PV reduction from existing PV penetration for the 23 ZS with greater than 1.5% peak reduction as the number of peak periods over which the average peak reduction is calculated varies.



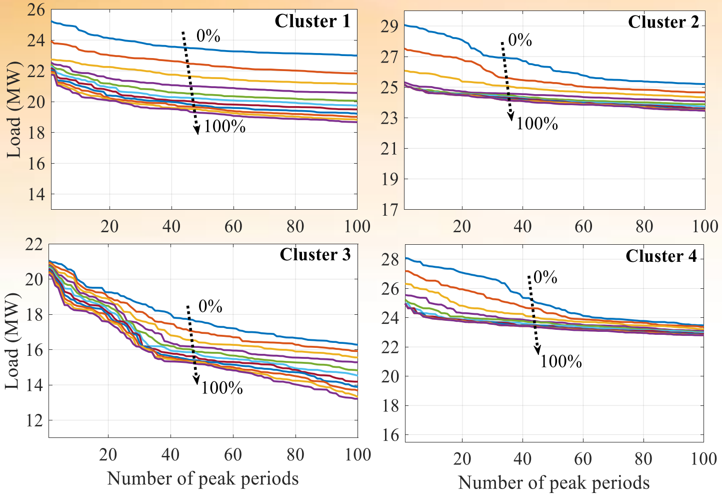
Clusters of PV performance in peak times of the 138 ZS - dotted lines are the clusters representatives, solid lines are the moving averaged smoothing of the representatives

Impact of Distributed PV on Zone Substation Peak Demand

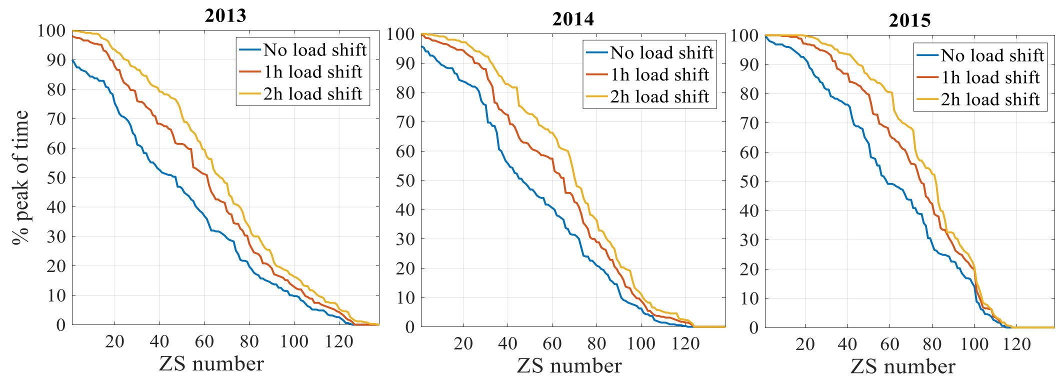
- PV systems performance availability for different ZSs and for different penetration level is estimated



PV availability over the top 1% of demand periods for each ZS over the years 2013, 2014 and 2015



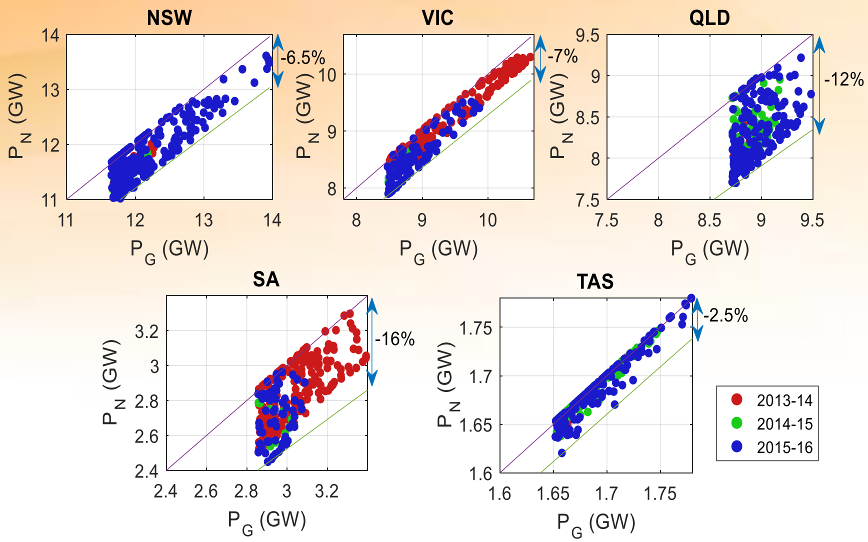
Load duration curve for one sample ZSs from each of the first four clusters



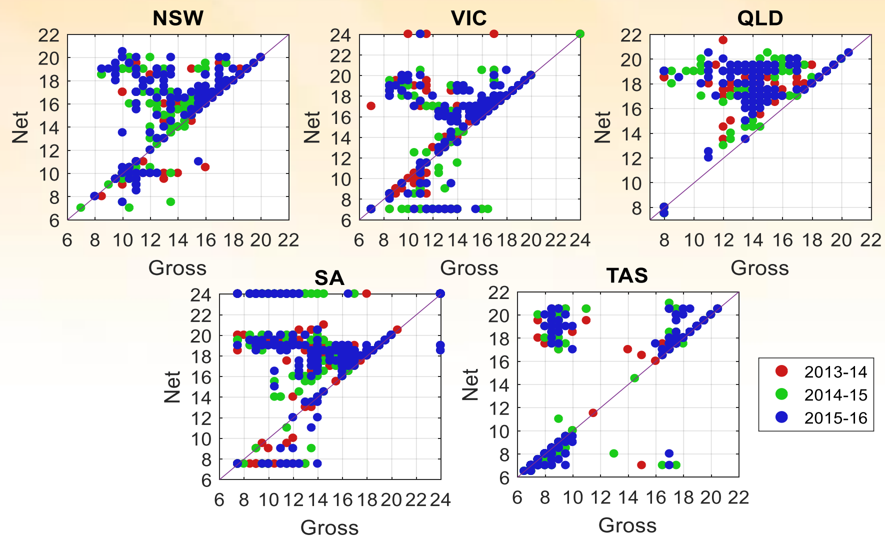
Trend of 0.3 PV availability for different options in different years across each ZS

Impact of PV on Peak Demand in Transmission Network Regions

- PV systems performance is upscaled by the capacity of PV installed in each **NEM region** to estimate the contribution and impact of PV



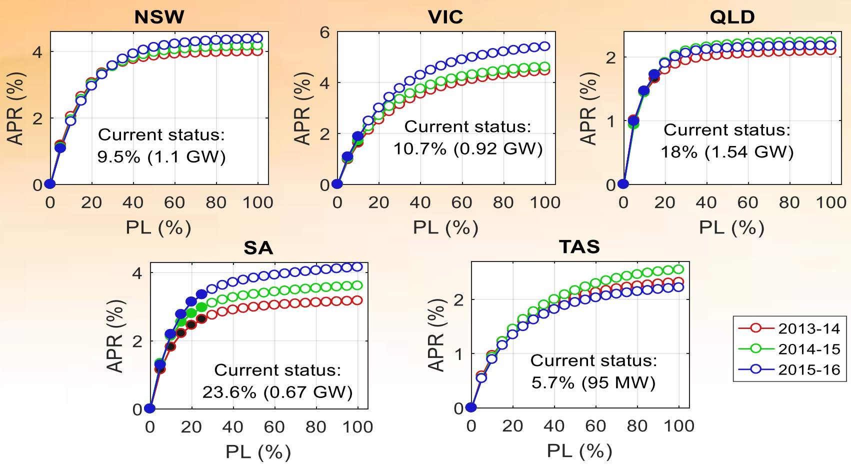
Net vs. gross demand in different states in top 0.5% of peak times. Range of peak reduction (%) is shown with a green line.



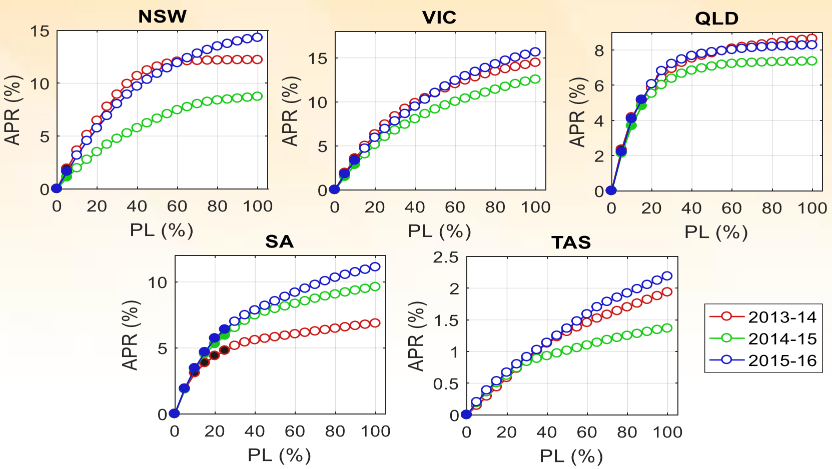
Peak time change for each day due to current solar contribution. x axis shows the peak hour in gross demand and y axis shows the peak hour in net demand

Impact of PV on Peak Demand in Transmission Network Regions

- The average peak reduction for each penetration level is estimated using historical data



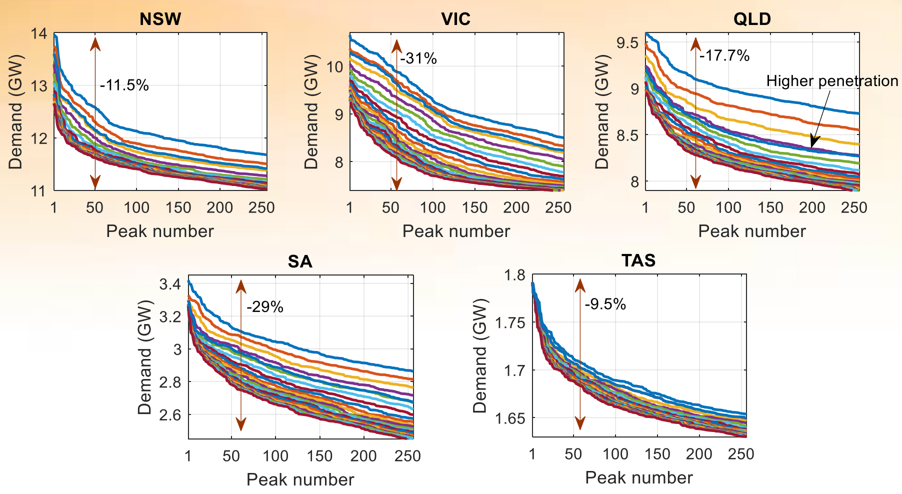
Impact of PV penetration on daily peak; average change in daily peak value (APR). Top filled circles represent current penetration level.



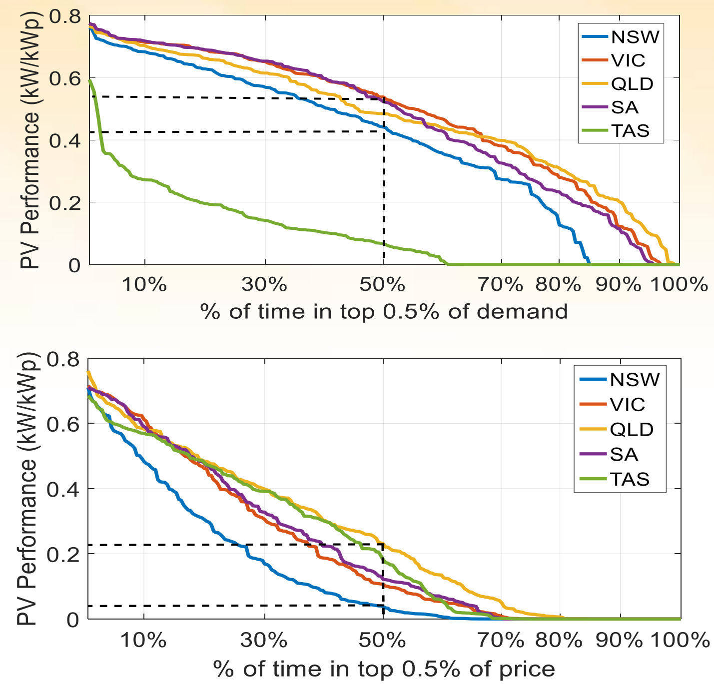
Impact of PV penetration on daily peak of the top 10 peak days; change in daily peak value (APR). Top filled circles represent current penetration level.

Impact of PV on Peak Demand in Transmission Network Regions

- Load duration curve for different penetration level and the availability of PV systems in the peak times are estimated



Demand duration curve for different PV penetration levels



PV availability across three years. Top: in top 0.5 of peak loads; bottom: in top 0.5% of price

Conclusion of the PhD

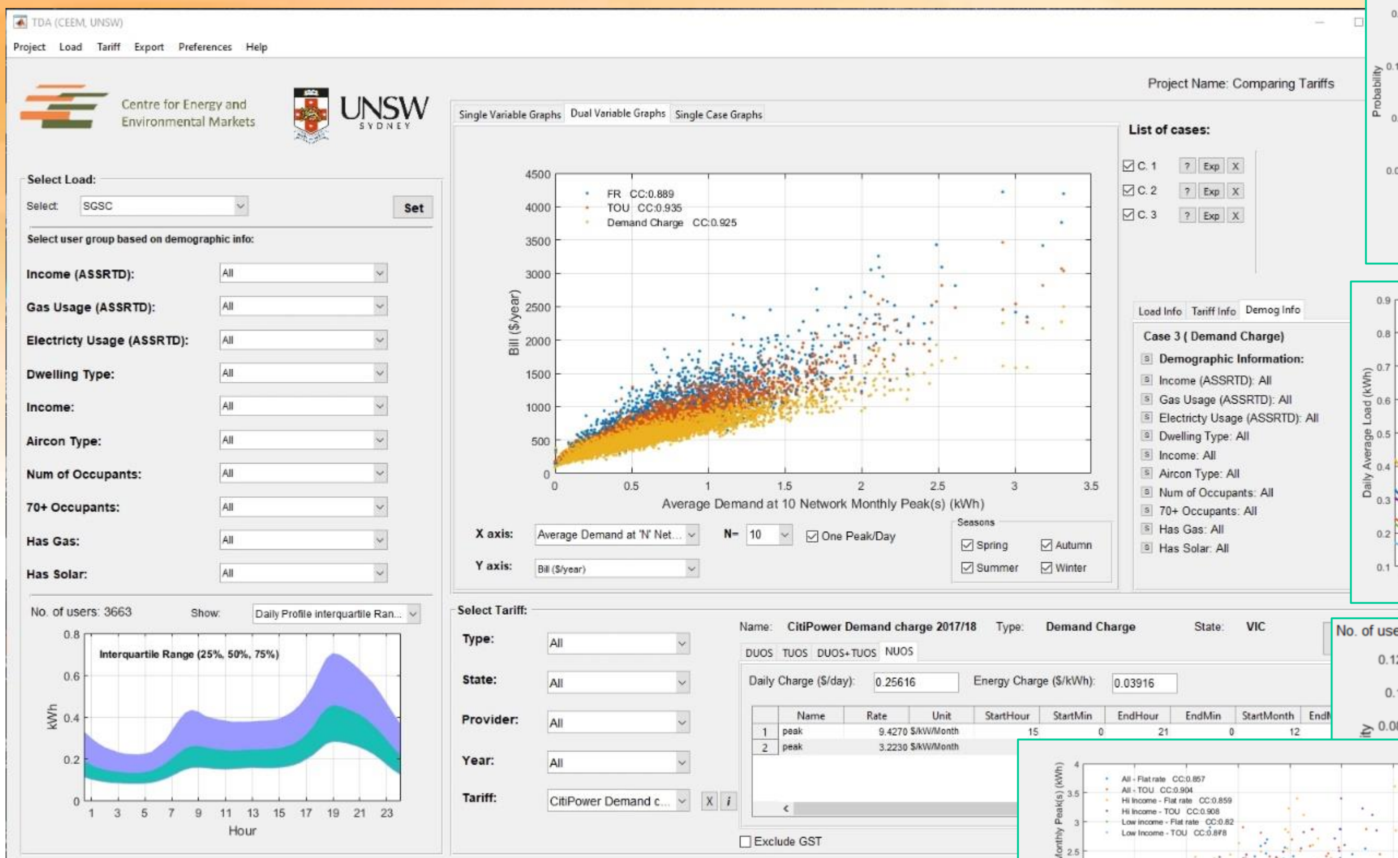
- A set of techniques introduced to improve the quality of data and metadata from distributed PV systems

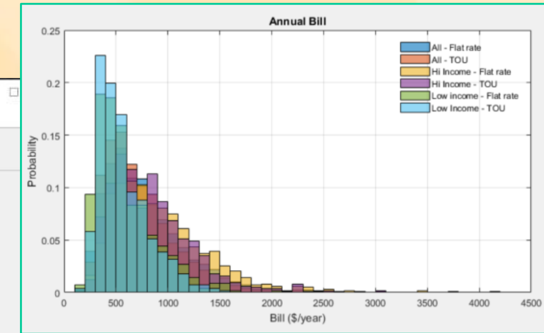
- The aggregate PV generation is estimated by upscaling the monitored systems

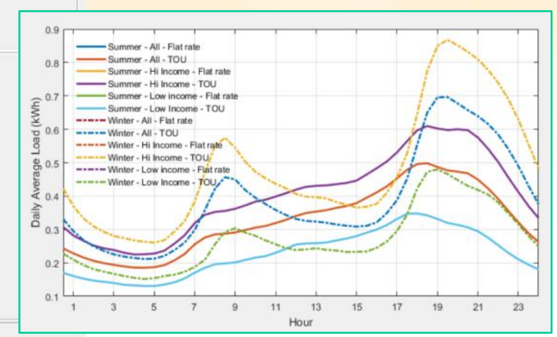
- The potential impacts of these systems on transmission and distribution networks are estimated

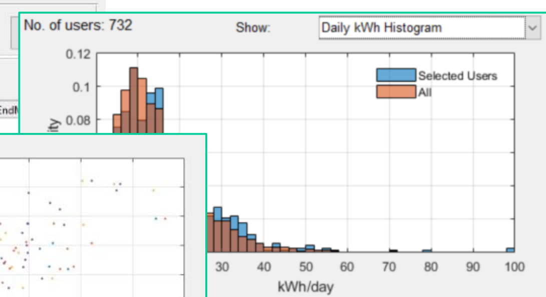
Side projects

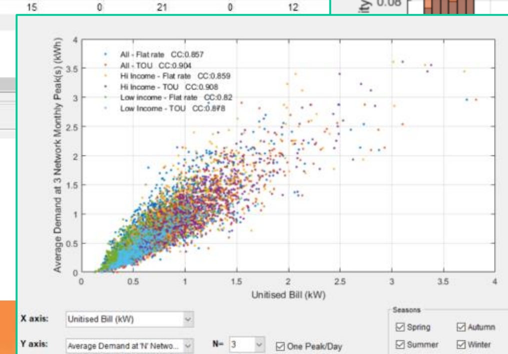
TDA: Open source tool for tariff analysis and design











https://github.com/UNSW-CEEM/TDA_Matlab

http://ceem.unsw.edu.au/cost-reflective-tariff-design

https://www.researchgate.net/project/Tariff-Design-and-Analysis-TDA-Tool

Funded by Energy Consumers Australia

Other open source tools at CEEM page

Open Source Tools

CEEM's researchers believe in the value of open source modelling in the Energy and Environmental research space. In this regard, we have developed a series of open source tools which are listed below. For a list of some of our under development tools you can refer CEEM's Github page.

Nem Data Tool:

Nem-data is a simple tool for creating custom data sets using publicly available information about th

Links: Github

National Electricity Market Optimiser (NEMO) Tool:

NEMO, the National Electricity Market Optimiser, is a chronological dispatch model for testing and c
electricity generation technologies. It has been developed since 2011 and is maintained by Ben Ellis
free software license (GPL version 3) and requires no proprietary software to run, making it particul
academic researchers and students. The model is available for others to inspect and to validate res

Links: Github, OzLabs

Tariff Design and Analysis (TDA) Tool:

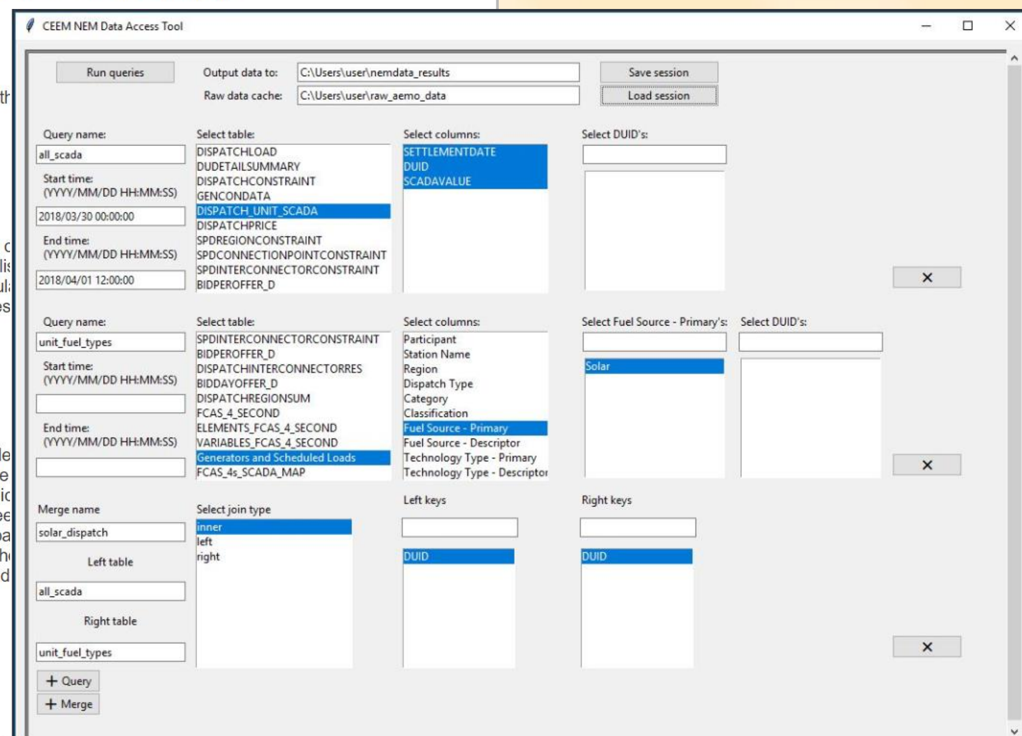
We have developed a modelling tool to assist stakeholders wishing to contribute to network tariff de
open source modelling tool to assist stakeholders in assessing the implications of different possible
engagement in the relevant rule making and regulatory processes in the NEM. Our tool takes public
NSW, and allows users test a wide range of existing, proposed and possible tariffs structures to see
Demographic survey data of the households allows you to explore the impacts of these tariffs on pa
children. The tool can also show how well different tariffs align these household bills with a househ
data are open source – you can check, validate and add your own data sets; test existing or even d
underlying algorithms.

Links: Project page, Github, Researchgate

Local Solar Sharing Scheme Model:

Intended for modelling embedded networks, local solar and peer to peer electricity networks. This s
and Rob Passey at CEEM. A working build with a simple user interface for OSX can be found here.

Links: Github



https://github.com/UNSW-CEEM/nem-data

Collaborations

- ***ITP/ UniMelb :*** *Arena-funded project, open source capacity expansion model*
- ***Rob Passey:*** Designing cost reflective tariffs
- ***Naomi Stringer:*** Security implications of the distributed PV systems particularly aggregate PV response to the system events (voltage and frequency excursions)
- ***Yusak Tanoto:*** Cost and reliability trade off in capacity expansion planning in Indonesia
- ***Mike Roberts:*** PV in apartment buildings
- ***Anam Malik:*** Contribution of residential Aircon and electric water heaters in peak demand
- ***Abdollah Ahmadi:*** Electricity generation scheduling in uncertain load/generation environment
- ***Nick Gorman:*** Open source simulator of NEM dispatch tool
- ***Mohsen Fadaeinejad***: Sustainable, environmentally friendly, and intelligent transport system

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