International Journal of Sustainable Energy Planning and Management Vol. 11 2016 15-32

International Journal of
Sustainable Energy Planning and Management

The effect of individual and communal electricity generation, consumption and storage on urban Community Renewable Energy Networks (CREN): an Australian case study

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ABSTRACT

Community Renewable Energy Networks, in which households and businesses in a local community share energy resources, are an attractive platform for optimising renewable energy use and reducing dependence on the wider electricity grid. However, the optimal use of local power generation and energy storage is critically dependent on the load characteristics and location of the community. In this work we compare the simulated energy generation, consumption and independence of two model developments in Melbourne and Sydney. The analysis looks at 6 basic scenarios, from the default grid dependence through to a community approach with both individual and communal photovoltaic (PV) generation and battery energy storage. The results show that a combination of household and community owned PV and storage can reduce grid electricity import by up to 93% for Melbourne and 96% for Sydney, but that neither development could independently meet all its power requirements without shortfall. The shortfall arises during the winter months when PV generation is at its lowest, and no practical amount of energy storage can mitigate this. Interestingly, Melbourne, which is at a higher latitude than Sydney and receives less solar insolation, achieves more months of grid independence than Sydney.

Key words:

Community renewable energy network, community energy, off-grid, community consumption, community generation
URL:
dx.doi.org/10.5278/ijsepm.2016.11.3

1. Introduction

A CREN is a smart microgrid, mostly based on renewable electricity generation, which is owned and operated by a community to supply for its own electricity needs and potential energy trading benefit [1]. In urban contexts, it relies primarily on photovoltaic generation at both individual dwelling and communal levels and on electricity storage.

In Australia, electricity generation is evolving towards less carbon emissions intensive fuels like gas and renewable sources [2] through implementations that range from large generators feeding the traditional grid to PV systems on rooftops providing for individual dwelling demand. Urban CREN provide the ideal opportunity – especially in a country as heavily urbanised as Australia - to harness the increasing environmental concerns and interest on energy independence that is making both communities [3] and corporations turn their attention to distributed renewable energy.

Industry conferences and consultancy appointments by both developers and local governments make it obvious that there is great interest in renewable energy for both greenfield and brownfield sites in urban and satellite-suburban environments. What used to be

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considered a solution for mostly remote communities with no access to traditional centralised electrification system is now becoming the focus for initiatives aiming at supplying distributed renewable energy solutions that allow varying degrees of independence from that, mostly fossil-fuelled, traditional grid. However the complexity presented by the combination of the technology and social aspects of community renewable energy systems [1], [4] has made their implementation difficult, given the holistic perspective that is required.

The academic literature contains many hundreds of articles on PV and microgrids, however to the best of our knowledge none of these deal with individual and communal electricity generation, consumption and storage on urban community renewable energy networks as investigated here. Comodi et al [5] recently reported on a six apartment residential microgrid in Italy, however this work did not compare individual and communal resources, and is at a much smaller scale than the work we report here. For a detailed review on the development of microgrids in general, we refer the reader to Mariam et. Al [6].

In our previous work [1] we proposed a transdisciplinary approach that considers both the technology and social requirements that community developers would need to address for the successful implementation of CRENs as their offering. We argued that it is necessary to acquire an adequate understanding of the true possibilities offered by a suitable combination of technology and business model that could make CRENs comply with (1) the community requirements, and (2) the shareholder value requirements that for-profit enterprises are committed to by both commercial interests and fiduciary obligations.

The purpose of this part of this transdisciplinary research is to understand the interaction and implications of renewable energy generation, consumption and storage within a microgrid and the benefits of centrally controlled local generation and storage in a real-world greenfield urban development in Australia. This study uses energy systems simulations with real-world data to compare six scenarios that range from the traditional default of no renewable energy (RE) or connection between dwellings to a fully interconnected community with (RE) and storage at both the individual and communal levels. The systems' performance is compared in terms of grid dependence and consequent CO_2 emissions, excess generation, and battery idle time to illustrate the difficulty in balancing the design of PV + storage systems with actual patterns of consumption. It is to be noted that costing of the system is not a consideration at this point of the study as the main focus at this stage is the understanding of the technology factors that will inform the financial and governance requirements of the consequent business model.

The rest of this paper is structured in four parts. Section 2 describes the model, the six scenarios, basic assumptions and formulations, and the constants and variables used in the simulations and modelling. Section 3 explains the data used, while Section 4 presents the analysed results, and Section 5 the conclusions of this study.

2. Model

Given that freely available software does not have the capacity of modelling intricate collective scenarios and proprietary packages with such capability are considerably complex, expensive and not commonly utilised by development businesses, the model has been completely developed as a spreadsheet model so that it can be used by any developer or business using its basic software suite.

The intention of the modelling is to understand the effects of electricity generation, consumption and storage in different individual and collective RE energy system configurations and to determine the environmental impact and the degree of autonomy afforded to the system by the sharing of assets at community level. The autonomy is measured in terms of MWh that need to be sourced from the grid and the environmental impact is measured by the greenhouse gas emissions savings that reductions in coal-fired electricity reliance imply.

2.1. Scenarios

As shown in Figure 1, six basic scenarios were considered:

1. Base – all dwellings, as per current default, are 100% grid-dependent
2. Individual solar system – each structure has its own system, comprised by only PV panels, and is individually connected to the grid
3. Individual solar system with storage – each structure has its own system, comprised by PV panels and electricity storage, and is individually connected to the grid
4. Community sharing individual systems through a central Energy Management System (EMS) –

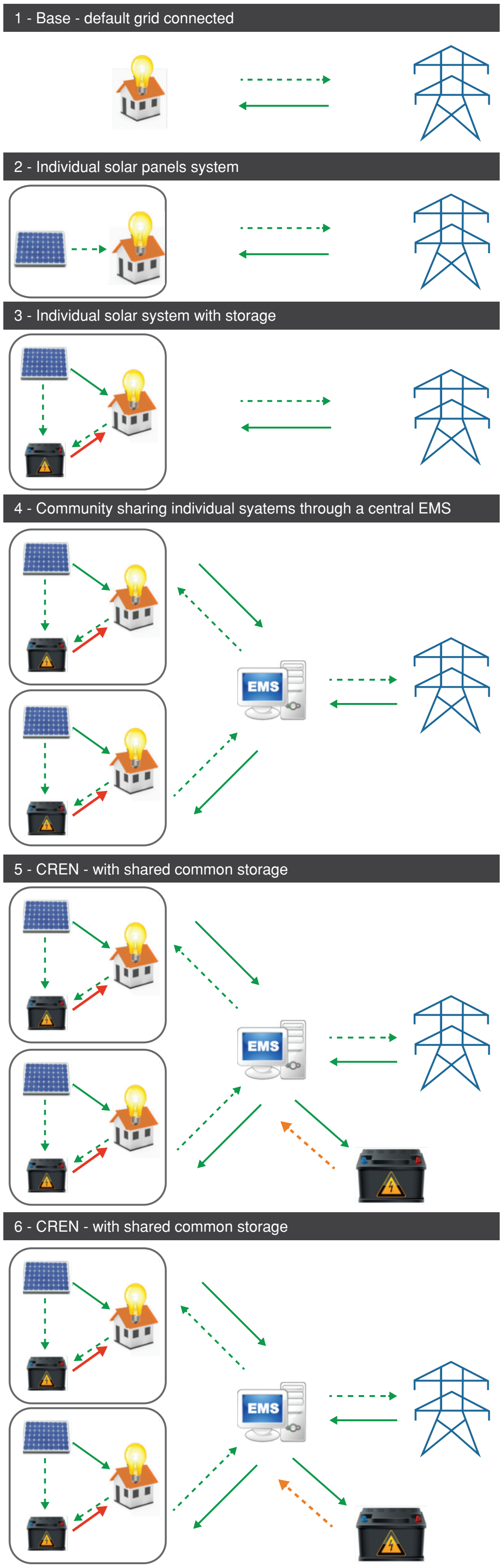


Figure 1: Scenarios

with all dwellings accessing the grid through a single connection point.

5. Community EMS managing individual systems and common storage – with all dwellings accessing the grid through a single connection point.
6. Community EMS managing individual and communal PV and storage systems – with all dwellings accessing the grid through a single connection point.

Base

In this case scenario, all dwellings fall into the historic default provided by developers for electricity supply; i.e. each dwelling, through its own connection, sources its electric power from the traditional grid. Electricity in this case is generated in remote coal fired plants, transmitted over high voltage wiring and accessed via local distribution networks.

Individual solar

It is assumed that every separate or semi-separate structure is provided by the developer with PV panels according to the possibilities offered by each dwelling typology. The renewable energy system of each dwelling functions completely independently of any neighbouring structures and the dwelling has its own connection to the traditional grid. The grid connection allows bi-directional flow of electricity.

Individual solar with storage

This case scenario, builds on the previous one by adding electricity storage capability to each individual PV system. The renewable energy and storage system of each dwelling still functions completely independently of any neighbouring structures and each dwelling has its own bidirectional connection to the traditional grid.

Community sharing individual systems through a central EMS

For this case scenario, a central EMS provides all the required functions to manage the operation of the microgrid formed by all the dwellings in that stage of the development. The centralised controller manages flow of electricity so that all loads are served either by an internal microgrid generator or the traditional grid and provides a single point of bidirectional connection to the grid for all the dwellings that are part of the microgrid.

CREN – with shared communal storage

The previous scenario is complemented by a centralised battery which is controlled by the EMS to provide further storage capability for all the dwellings in the CREN. This communal storage facility is only charged by excess electricity generated in the microgrid –i.e. surplus PV generation from individual systems after loads are served and individual batteries are fully charged.

CREN – with shared communal generation and storage

This last case scenario adds photovoltaic cells in common spaces – e.g. covering for footpaths and parking spaces, communal buildings and/or shaded areas, etc. - so that we have a CREN where: 1) every separate or semi-separate structure is provided by the developer with PV panels and electric storage according to the possibilities offered by each dwelling typology, 2) with these individual dwellings now forming part of a larger system in which a central controller manages the generation and use of electricity at a community level while providing a single point of connection to the traditional grid, and 3) besides the electricity generation and storage happening on individual dwelling structures, there is also electricity generation and storage in common areas.

2.2. Basic assumptions and formulations

For all scenarios

- every year for every lot starts on hour 1 of 01 January and ends on hour 24 of 31 December
- battery charge is a continuous calculation that starts on 01 January and ends on 31 December taking into consideration generation and consumption for every hour of every day
- there always is a load

For the individual solar scenario

- when there is local generation:
  - local load is served first
  - any excess electricity after local load service goes to grid
- when there is no local generation load is served by grid

For the individual solar with storage scenario

- when there is local generation:
  - local load is served first
  - any excess electricity after local load service goes to local battery
  - if battery is full, excess goes to grid
- when there is no local generation and local battery has charge:
  - if local load is less than the remaining local charge, load is served from local battery
  - if local load is greater than charge, then load is served by local battery and grid
- when there is no local generation and local battery has no charge, local load is served from grid

For the community sharing individual systems through a central EMS scenario

- when there is individual local generation:
  - individual local load is served first
  - if individual local generation not enough to serve load:
    - as much load as possible is served by individual local generation and deficit is:
      - supplied by EMS with excess generation from other systems in the microgrid
      - if excess generation from microgrid not enough, EMS serves load from grid
  - any excess electricity after local load service goes to local battery
  - if local battery is full, excess is acquired by EMS for allocation
- when there is no individual local generation and individual local battery has charge:
  - if individual local load is less than the remaining individual local charge, load is served from individual local battery
  - if individual local load is greater than charge, then load is served by individual local battery and:
    - excess generation from other dwellings allocated by the EMS
    - if excess generation available to the EMS is insufficient, load is served through the EMS from the grid
- when there is no individual local generation and individual local battery has no charge:
  - if there is excess generation available to the EMS, load is served by EMS allocation

  - ❍ if no excess generation is available to the EMS, load is served through the EMS from the grid

For the CREN – with shared communal storage scenario

- when there is individual local generation:
  - ❍ excess local generation from individual systems (i.e. individual PV panels + individual battery) charges the communal battery
  - ❍ individual local load is served first
  - ❍ if individual local generation not enough to serve load:
    - ■ supplied by EMS with excess generation from other systems in the microgrid
    - ■ if excess generation from other systems in the microgrid not enough to serve load, and there is charge in communal battery:
  - ❍ if there is enough charge in communal battery, load is served from communal battery
  - ❍ if there is not enough charge in communal battery, load is served from community battery and deficit is supplied through the EMS from the grid
- if no local excess generation available, load is served through the EMS from communal battery:
  - ❍ if there is enough charge in communal battery, load is served through the EMS from communal battery
  - ❍ if there is not enough charge in communal battery, load is served through the EMS from community battery and deficit is supplied through the EMS from the grid
- if communal battery has no charge, load is served through the EMS from the grid:

For the CREN with shared generation and storage scenario

- there are PV modules installed, wherever possible, in common areas
- when there is local generation:
  - ❍ excess local generation from individual systems (i.e. individual PV panels + individual battery) charges the communal battery
  - ❍ communal PV panel charge communal battery
  - ❍ individual local load is served first
  - ❍ if individual local generation not enough to serve load:
    - ■ load is served by EMS with excess generation from other systems in the microgrid and/or with generation from communal PV panels
    - ■ if overall generation from the systems in the microgrid not enough to serve load, and there is charge in communal battery:
      - ❍ if there is enough charge in communal battery, load is served from communal battery
      - ❍ if there is not enough charge in communal battery, load is served from community battery and deficit is supplied through the EMS from the grid
- if no local generation available, load is served through the EMS from communal battery:
  - ❍ if there is enough charge in communal battery, load is served through the EMS from communal battery
  - ❍ if there is not enough charge in communal battery, load is served through the EMS from community battery and deficit is supplied through the EMS from the grid
- if communal battery has no charge, load is served through the EMS from the grid:

2.3. Variables

The number of panels per typology remains a constant throughout all the different cases studied and are

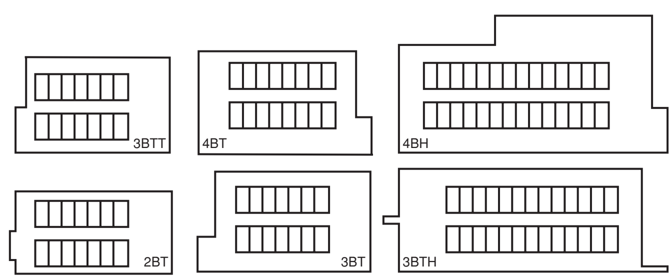


Figure 2: Dwelling typologies - 2BT - 2-bedroom terrace; 3BT - 3-bedroom terrace; 3BTH - 3-bedroom townhouse; 3BTT - 3-bedroom 3-storey terrace; 4BT - 4-bedroom terrace; 4BH - 4-bedroom house

determined by the roof space available, taking into consideration structural limitations, tilt of arrays and circulation requirements for servicing and maintenance of systems.

The storage capacity per number of PV panels can be varied to test the impact of storage on the performance of the systems to meet demand. The variation affects the systems according to the number of PV panels per dwelling, regardless of architectural typology, so that the system is determined by the space limitations thus allowing diverse consumption bands for the same technology configuration. This way the same system configuration – like, for example, those on 2 bedroom terraces and on 3 bedroom 3 storey terraces - supply a wider range of consumption patterns that better resemble real-world occurrences. For the purpose of this study, the generation and storage capacities for each dwelling typology are as set out in table 1.

The other two variables are the number of PV panels to be installed in the common spaces of the community public areas and the storage capacity of the central battery.

The results were obtained by running weather simulations and modelling the performance of each scenario for the second stage of the proposed development. This second stage was chosen because it has the largest amount – 81 - of separate and semi-separate dwellings within all five bands of consumption and a prevalence of small to medium-sized RE systems.

Table 1: Configuration of solar generation and electricity storage systems per typology

Typology	PV panels	Power (kW)	Battery (kWh)	Sto/Gen ratio
2BT	22	5.4	12	2.2
3BT	22	5.4	12	2.2
3BTH	26	6.4	18	2.8
3BTT	22	5.4	12	2.2
4BH	28	6.9	18	2.6
4BT	24	5.9	15	2.6

Table 2: Aggregate generation and storage capacity installed on individual dwellings (totals) of Stage 2 of the proposed development

Typology	Dwellings	PV panels	Power (kW)	Battery (kWh)
2BT	29	638	156	348
3BT	6	132	32	72
3BTH	12	312	76	216
3BTT	16	352	86	192
4BH	8	224	55	144
4BT	10	240	59	150
Totals	**81**	**1898**	**465**	**1122**

The System Advisory Model (SAM) [7] provided by the US National Renewable Energy Laboratory to the renewable energy industry was used for the weather simulations to calculate the electricity generated by the PV panels on each individual dwelling – SAM does not have the capability to model collectives. The simulations were run with an array of 22 modules divided into two strings of 11 modules each with one inverter per array. The characteristics are provided in Tables 3 and 4.

Eight simulations were run with the above configuration to account for the different orientations of the roof areas on which the PV modules were to be placed within the development. The different azimuth and tilts for each simulation are provided in Table 5:

The azimuths correspond to the orientation of the dwellings in the development and the tilts to the latitude of the location as is normally recommended. The results for PV generation obtained by the simulations were then applied to the typologies with 22 PV panels on the roof while for the other typologies and for the central generation a factor was applied for the corresponding number of panels in proportion to 22.

Table 3: Photovoltaic module specifications – Sunpower SPR-E20-245 [8]

PV modules:

Efficiency	Power at maximum power (W)	Temperature coefficient % / ˚C	Temperature coefficient W / ˚C	Voltage at maximum power (V)	Current at maximum power (A)
19.7	245.0	–0.3	–0.7	40.5	6.1

Table 4: Solar system inverter specifications – Xantrex GT5.0 240V

Inverter:	Maximum power (W)		Nominal voltage (V)		Consumption (Wh)	
Efficiency	AC	DC	AC	DC	operation	night
95.4	5000	5285	240	299.7	27.2	1

Table 5: Azimuth and corresponding tilt angles for solar systems on development dwellings

Azimuth	0˚	2˚	7˚	41˚	272˚	277˚	311˚	341˚
Tilt	38˚	38˚	38˚	38˚	30˚	30˚	38˚	38˚

3. Data

Solar irradiation data for the simulations was provided by the International Weather for Energy Calculations (IWEC) which is based on climatic observations of specific weather stations over the preceding 25 years. The Melbourne airport, -37.67˚N and 144.83˚E, and Sydney airport weather stations, -33.95˚N and 151.18˚E, provided the records used for the PV system generation simulations.

The electricity emission factors for end users for Melbourne -1.35 kg $CO2_e$/kWh- and Sydney -0.99 kg $CO2_e$/kWh- were sourced from the Essential Services Commission of the Victorian Government [9] and the Department of Environment of the Commonwealth of Australia [10]

The input data for the model comprises real-world time series of electricity consumption for 300 homes in the local area of the proposed development in Melbourne and 300 homes in an equivalent suburb in the metropolitan area of Sydney. This electricity consumption data, as measured by smart meters, is aggregated to a temporal resolution of 1 hour intervals to coincide with the interval resolution available from SAM for the PV electricity generation. Using the amount of electricity used per dwelling, these 300 individual customer records for each local area are divided into 5 bands which correspond to the number of persons per dwelling that, on average, would use that amount of electricity per year. The value references for the bands was sourced from the Australian Federal Government [11] home electricity usage benchmarks for the suburb of the proposed development and its equivalent in Sydney. The bands are then used to match consumption with the different dwelling typologies.

The urban development data was provided by an Australian housing estate developer intending to develop an old quarry site in an Eastern suburb of Melbourne. They supplied masterplans (Figure 3) and high-level building characteristics for this greenfield, 778-dwelling development planned for completion in six discrete stages over a yet to be determined number of years. The second stage of this development, comprising 81 single dwelling buildings, provides the base housing data for the modelling. The same development data was utilised for the Sydney model. For the purpose of this research, each stage is considered to be a separate CREN.

Figure 3: Proposed development masterplan

There are nine different plan typologies for the separate and semi-separate dwellings. All structure envelopes have a flat roof with a 2˚ slope for water runoff towards what is considered the back of each building.

Figure 4 summarises some of the more important climatic factors affecting results of RE system implementations:

Ambient temperature affects consumption aimed at providing comfortable internal environments in households.

During the cooler months of the year, Sydney has greater solar exposure than Melbourne and, in general, less cloud obstruction as well.

According to the Australian Bureau of Meteorology (BOM) [14], 2014 was a particularly warm and dry year for Melbourne:

- equal warmest year on record for mean temperatures
- warmest year on record for minimum temperatures in many suburbs
- maximum temperatures warmer than average
- rainfall below to very much below average
- four consecutive days above 41°C from 14 January
- warmest winter overnight minimum temperatures on record, with July specially mild
- coldest night: 03 August

The BOM [15] also recorded a very warm and dry year for Sydney in 2014 :

- equal warmest year on record for minimum temperatures
- second warmest year on record for mean and maximum temperatures
- second fewest number of cool days on record
- driest year since 2005
- coldest nights: 09 and 12 July

No financial data was considered for this part of the research as all cost and revenue structures are part of the next stage of the study.

4. Results and discussion

When aggregating the electricity generation from the PV panels per dwelling to annual values and comparing these

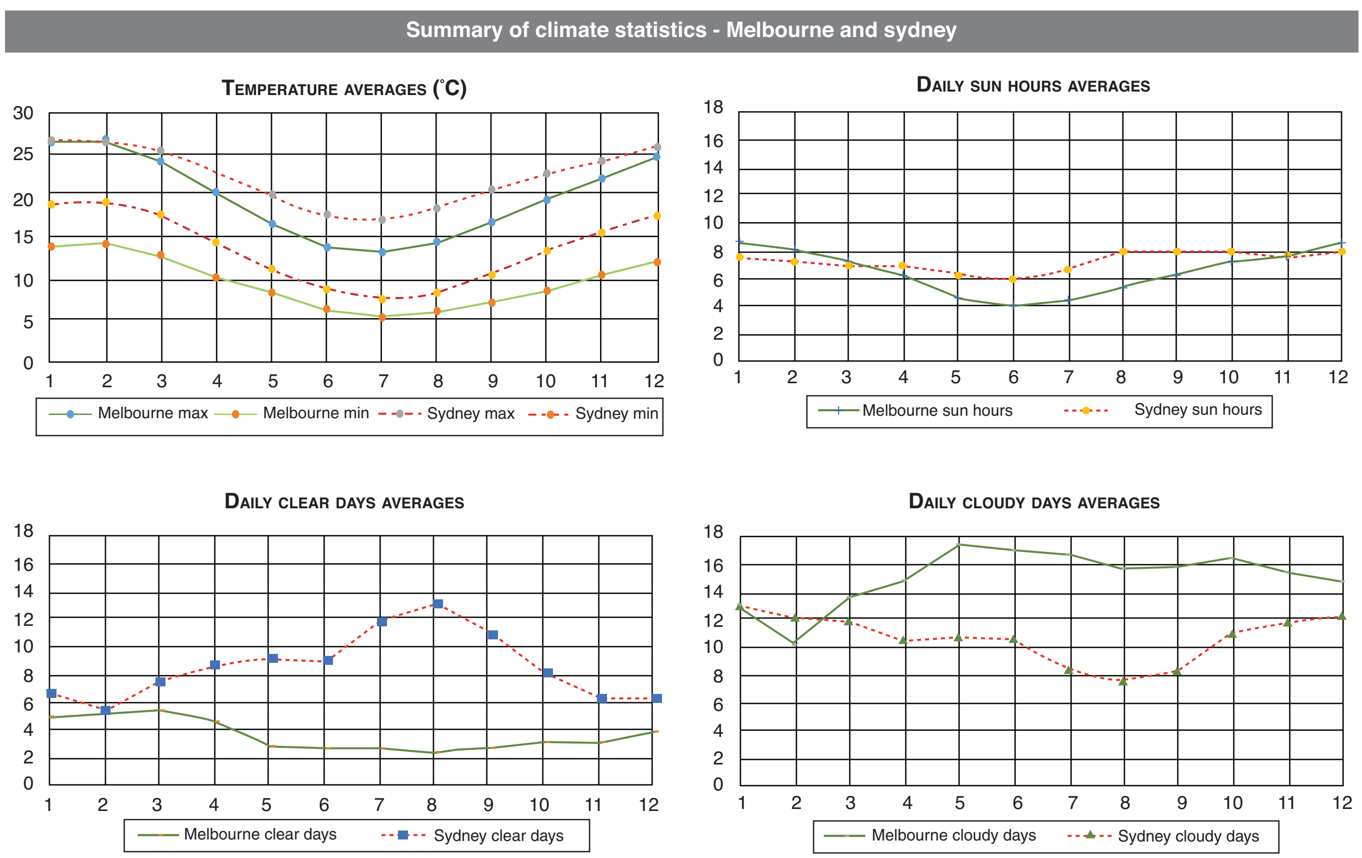


Figure 4: Summary climate statistics – Melbourne [12] and Sydney [13] minimum and maximum temperatures and solar exposure

values to their corresponding aggregated consumption, overall generation exceeds overall consumption by over 39% in Melbourne and by over 45% in Sydney. On annual averages, generation supplies for the consumption of over 98% of all dwellings in either city.

Table 6 summarises† grid dependence on an annualised basis, showing the annual reduction in grid dependence and consequent GHG emissions ranges from 42% for the individual PV systems in Melbourne to 96% for the CREN implementation with communal storage and generation in Sydney.

When adding just solar panel systems on individual dwellings, Melbourne achieves a slightly larger reduction (42%) in grid dependence than Sydney (40%). However, when adding storage at any level – individual or communal - the advantage in grid dependence reduction shifts to Sydney.

The larger drops in grid dependence, in either location, are achieved by the addition of storage: the installation of just photovoltaic panels reduces demand on grid by 42% in Melbourne and 40% in Sydney, while the addition of storage renders a reduction of 84% in Melbourne and 87% for Sydney.

Bringing all individual systems together through a centralised Energy Management System (EMS) produces only a 1% improvement - relative to base - for both Melbourne and Sydney. The relatively small gain is a result of the fact that all systems are generating at the same time so only the most extreme/ largest users benefit from the sharing of resources.

Adding communal storage shared through the centralised EMS, reduces the residual grid dependence by 33% in Melbourne and 54% in Sydney (5% and 7% relative to base, respectively), and installing communal solar generation shared through the same EMS, provides a further reduction, relative to base, of 3% for Melbourne and 2% for Sydney. The increase of storage has a slightly larger effect, relative to base, in Sydney than in Melbourne while the increase of generation capacity – i.e. solar modules - has a slightly larger effect in Melbourne. This is due to the fact that Sydney, because of climatic conditions, has larger generation with the same number of solar modules which, without additional storage, just translates into more excess electricity.

Even though sharing common resources at community level with a CREN implementation roughly halves the residual grid dependence and emissions of the individual PV and storage scenario, in all, relative to base, it only provides an additional improvement of between 9% in Melbourne to 10% in Sydney. Overall, the grid dependence of the development with a CREN implementation incorporating communal generation and storage is reduced by 93% in Melbourne and 96% in Sydney.

Table 6: Grid dependence (MWh) and consequent greenhouse gas emissions (t CO2e) from electricity production

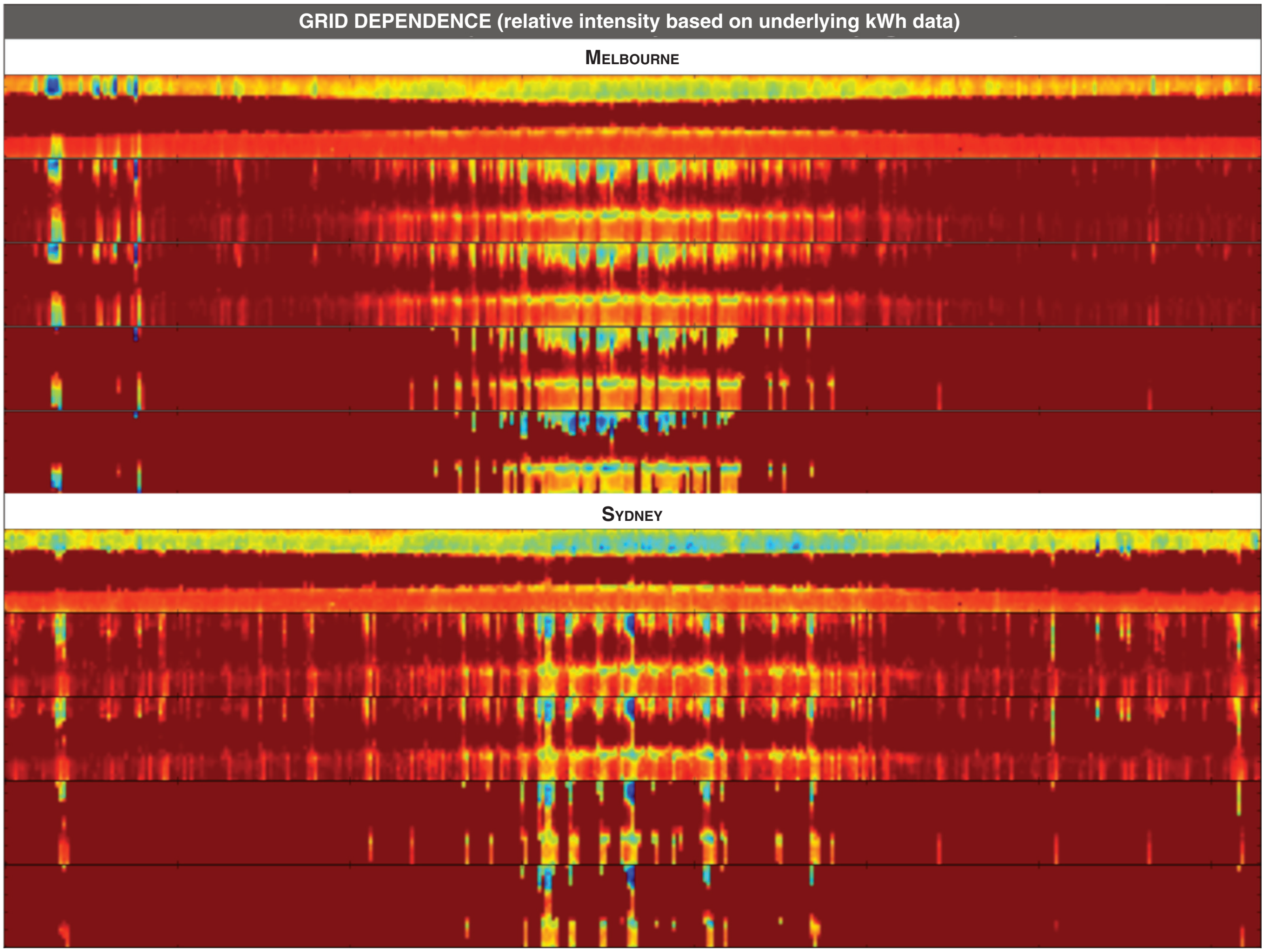
	Melbourne			Sydney		
	MWh	tCO_2e		MWh	tCO_2e	
Base	378	511	100%	353	476	100%
Individual solar	220	298	58%	212	286	60%
Individual solar + storage	59	80	16%	50	67	14%
Community EMS	58	78	15%	47	63	13%
Community EMS + storage	36	49	10%	20	27	6%
Community EMS + storage + PV	28	37	7%	13	17	4%

From a more detailed viewpoint, as shown on the heatmaps in Figure 5, from seasonal, monthly, daily and hourly perspectives, the demand on supply from the traditional grid remains quite considerable during certain periods when generation is low and consumption is high. It can be seen in the lower band – CREN with communal storage and generation - that what seems a very small residual dependence on grid at an annualised level is actually a considerable daily demand during the winter months, especially for Melbourne.

The different latitudes with their implied effects on temperature and longer daylight hours, mean that in Melbourne, the largest loads due to seasonal factors happen during winter months, while in Sydney, though also peaking during winter, loads catering for temperature control and lighting are more evenly spread through the year.

It is to be noted that the particular weather extremes for Melbourne in 2014 affected the results of the modelling with consumption patterns slightly different to average. For example, the four consecutive days of temperatures above 41˚C during the 14 to 17 January period are noticeable in a spike in the overall consumption pattern. Without this unusual heat wave, the concentration of grid dependence in Melbourne during winter would be even more pronounced. Though not as a discernible spike, the record lowest daily maximum temperature (6.6˚C on 22 July) and the warmest winter overnight minimum temperatures on record are likely to have modified the average consumption as well.

† Detailed tables, with per dwelling data, available upon request.



1. First band: Scenario: Solar panels on individual dwellings with no storage **2.** Second band: Scenario: Solar systems - PV panels and storage- installed on individual dwellings **3.** Third band: Scenario: Community sharing individual systems through a central Energy Management System (EMS) **4.** Fourth band: Scenario: Community EMS managing individual systems and storage in common areas **5.** Fifth band: Scenario: Community EMS managing individual systems and storage and generation in common areas.

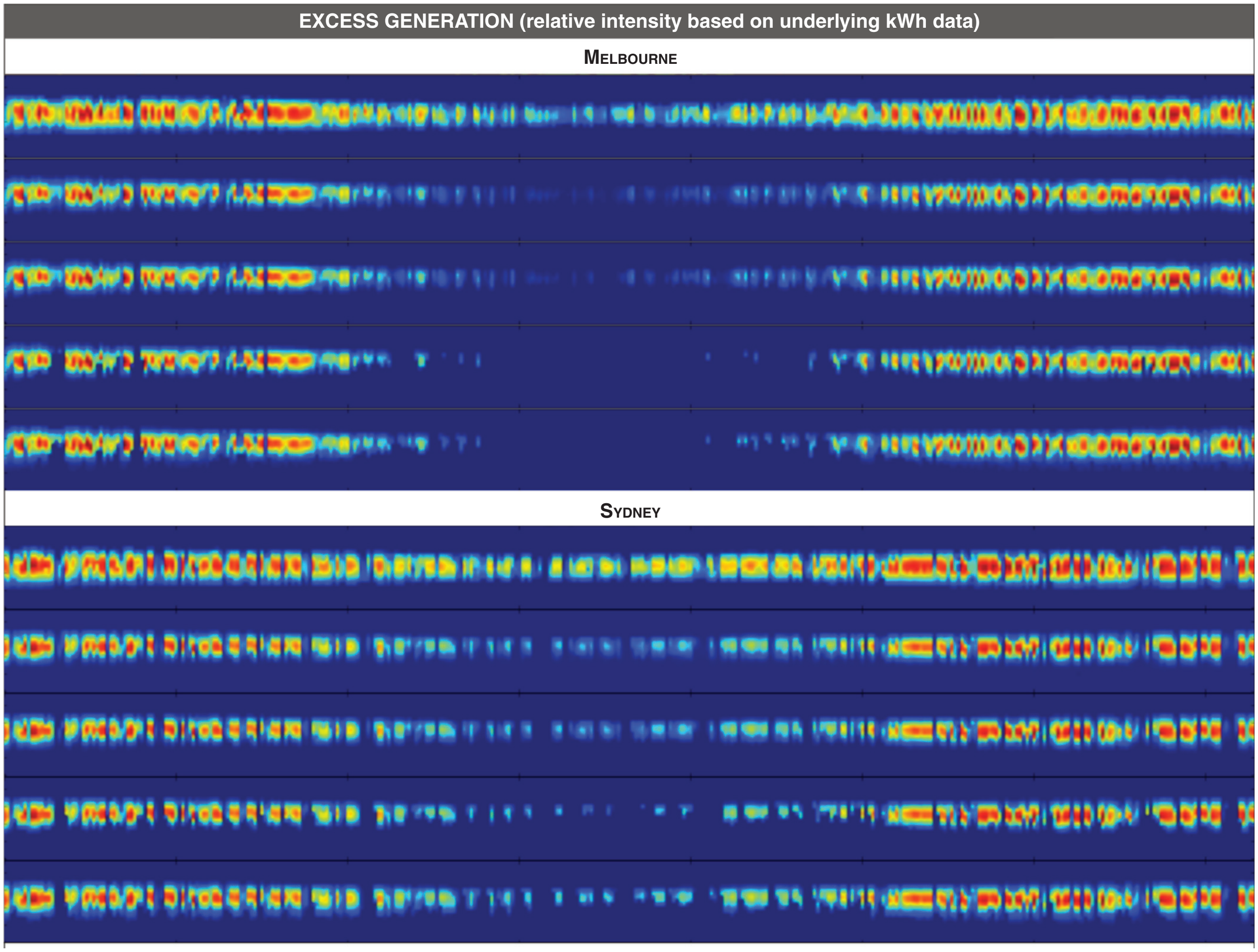
The vertical axis of each band represents the 24 hours of each day while the horizontal axis represents the 365 days of the year.
The colour scaling goes from dark red for the lowest values to blue for the highest values of grid dependence for each scenario.

Figure 5: Heat maps of demand on grid supply for scenarios in Melbourne and Sydney

Even though the record-breaking high minimum temperatures during winter nights in Melbourne are likely to have resulted in a weaker pattern of consumption that made the normally higher peak for this period less pronounced, the demand on the grid is, however, still notably more intense than in Sydney.

Outside the winter peak – except during the extreme heatwave in the second half of summer - Melbourne has a lower pattern of grid dependence than Sydney after the implementation of photovoltaic systems, with or without storage at individual level. Other than during the winter months, Sydney households in the first three scenarios required relatively more energy from the grid than Melbourne households. However, under the CREN scenario with communal generation and storage, Sydney is considerably closer to grid independence than Melbourne because of the lower winter peak.

Figure 6, showing the electricity generated in the community that is not used at either individual or collective level, provides a clear picture of the contrast between the supply and demand at different times of day and different times of year. Indeed, when comparing the heatmaps for grid dependence and excess generation, it becomes obvious that the systems are over



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The vertical axis of each band represents the 24 hours of each day while the horizontal axis represents the 365 days of the year.
The colour scaling goes from dark red for the lowest values to blue for the highest values of grid dependence for each scenario.

Figure 6: Heat maps of excess electricity generated by solar systems for scenarios in Melbourne and Sydney

specified, in terms of capacity, for most of the year and insufficient when the winter demand increases due to lower temperatures and shorter days.

Melbourne has no excess generation in June when electricity storage is installed on individual dwellings, and no excess generation in June or July when storage in common spaces is made available to the community, while Sydney has excess generation all year because of its more northern latitude implying milder temperatures and larger solar exposure during winter.

Figure 7, shows the ratio of photovoltaic generation to consumption for the communities in the Melbourne and Sydney contexts. Again, when studied from larger perspectives – in this case seasonal -, the averaging produces a "kinder" picture than the more detailed viewpoints. In seasonal averages, Melbourne goes from an average maximum ratio of generation of 2.2 times consumption during spring to 0.87 during winter, while Sydney goes from a high of 2.42 for spring to a low of 1.19 in winter. Bringing the standpoint to monthly averages, results in Melbourne's ratios dropping down to 0.79 and 0.66 for July and June respectively, while Sydney's apparent sufficiency drops to 0.99 in June.

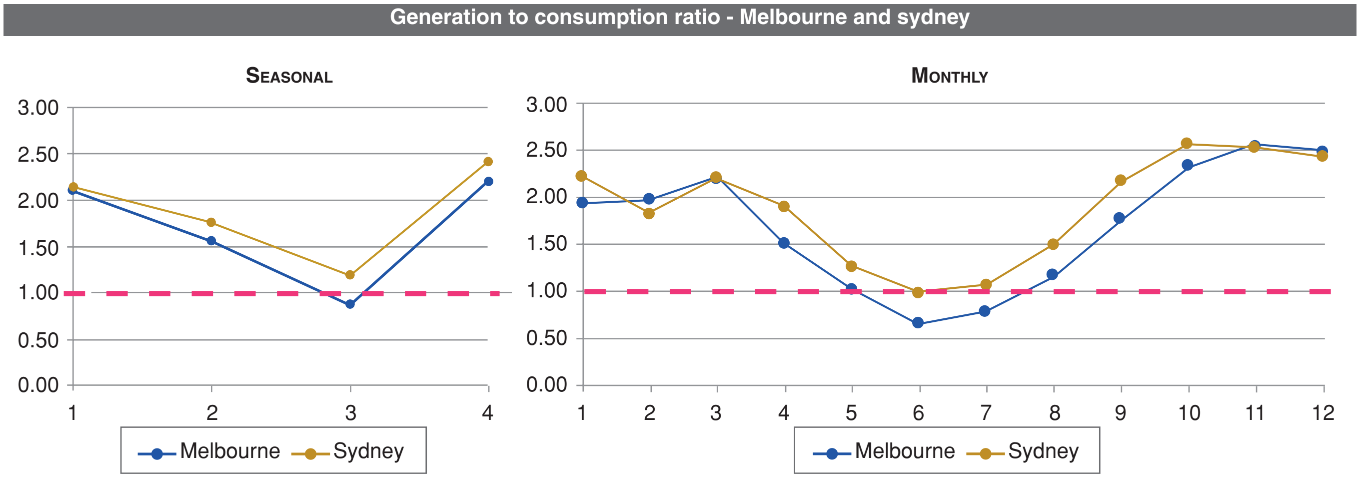


Figure 7: Comparison of generation to consumption ratio in Melbourne and Sydney

Figure 8 shows daily averages for June, the month of the year that implies the largest negative gap between generation and consumption for both cities. The dashed straight lines indicate the averages for the month and show a considerable gap (390 kWh) between the average monthly generation and consumption for June in Melbourne and a very small gap (10kWh) for Sydney. This averaging would suggest that the system requirements for the northern city could be considerably less than those for Melbourne.

However, a somewhat more accurate daily perspective reveals that the system requirements for Sydney are larger because its peaks and troughs, as Table 7 summarises, for both generation and demand present a more pronounced gap.

Table 7: Maximum and minimum generation, consumption and generation to consumption ratios for Melbourne and Sydney – June notables

	Melbourne		Sydney	
Max. generation (MWh)	1.13	0.86	1.63	1.41
Min. generation (MWh)	0.27		0.22	
Max. consumption (MWh)	1.39	0.36	1.31	0.41
Min. consumption (MWh)	1.03		0.91	
Max. G/C ratio	1.00	0.77	1.70	1.53
Min. G/C ratio	0.23		0.17	

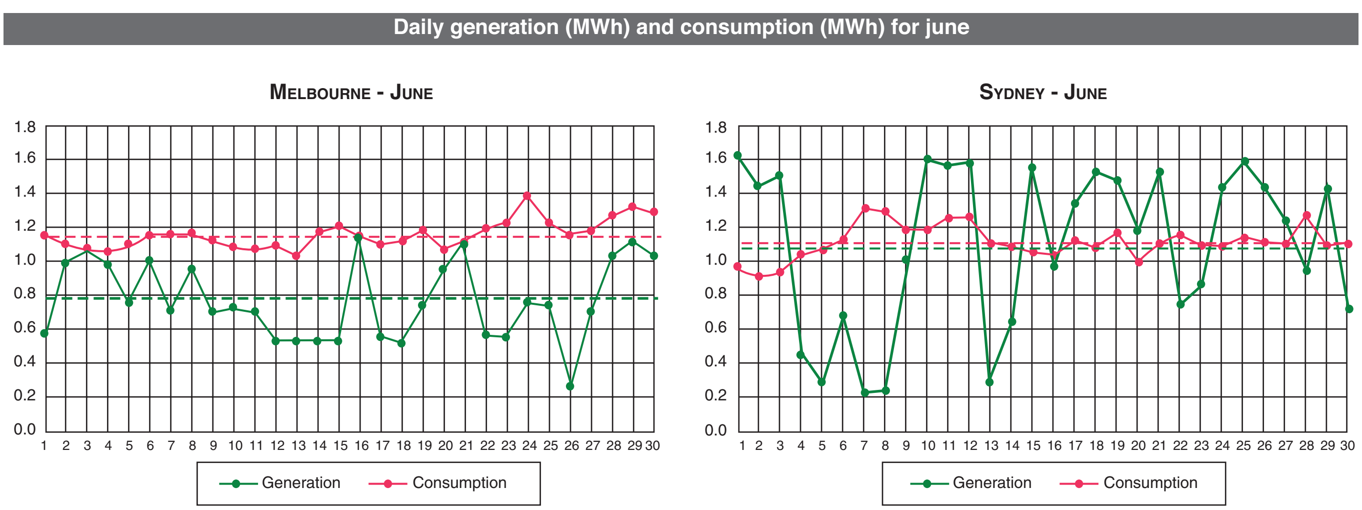


Figure 8:. Comparison of average daily generation and consumption in June for Melbourne and Sydney

In Melbourne, the difference between maximum and minimum daily generation never exceeds 0.86 MWh (1.13 max – 0.27 min), while in Sydney the range goes from 1.63 MWh to 0.22 MWh (1.41 MWh) - 64% larger. Daily average consumption also presents a greater gap (0.41 MWh) between maximum (1.31 MWh) and minimum (0.91 MWh) in Sydney than in Melbourne (0.36 MWh gap, 1.39 MWh max, 1.03 MWh min). Despite June comprising Melbourne's largest gap day (26 June) and Sydney's only second largest (07 June), when matching minimums and maximums in a generation to consumption ratio, the dissimilarity becomes even more evident with the northern location presenting a roughly double (99%) variation in ratio (1.53, from 1.7 max to 0.17 min) than the southern site (0.77, from 1 max to 0.23 min). It is also quite notable that even the worst day for Melbourne, in terms of generation to consumption, is still better than the second worst in Sydney, 0.23 to 0.17 respectively.

Further detailing confirms that, even though Melbourne has worse deficit ratio averages during the winter months, its daily lowest generation to consumption ratio during the year (0.23 on 26 June) is between 53% and 28% higher than Sydney's three lowest (0.15 on 02 July, 0.17 on 03 June, and 0.18 on 07 June).

Figure 9, shows the hourly generation and consumption during the 24 hours of the lowest generation to consumption days for Melbourne and Sydney.

Notwithstanding the fact that it is only one day, this 24-hour period means that to achieve grid independence it would be necessary to design the supply system – i.e. diverse types of generation and storage - at least the same for both cities, in spite of the apparent advantage that Sydney would be expected to have given its further northern latitude. Catering for this day would mean that a large proportion of the resources – both generation and storage - are wasted for most of the rest of the year.

It is such extremes as this pattern of consumption in Sydney during a day of low generation that make demand side management imperative for the efficient performance of the renewable energy implementations. Rather than over specifying systems for extremes, it is a more rational use of resources to allocate the investment to reducing the demand in first place.

Though not as acutely as an hourly perspective of a low generation to consumption ratio day, Figure 10, on monthly averages, clearly emphasises the waste that accommodating large peaks of demand imposes on photovoltaic with storage systems.

Despite Sydney having the lowest generation to consumption ratio, Melbourne's winter overall divergence between increased demand and reduced solar exposure is more pronounced than that in Sydney, especially when storage is available to capture the additional solar exposure of the northern city.

Due to the deviation between times of generation and times of use, there is demand on the grid even when battery idle time is considerable – e.g. 58% of total hours of battery idle time in January in Melbourne while there is the need to still source electricity from the grid for over 4% of the time, albeit in small quantities (4kWh).

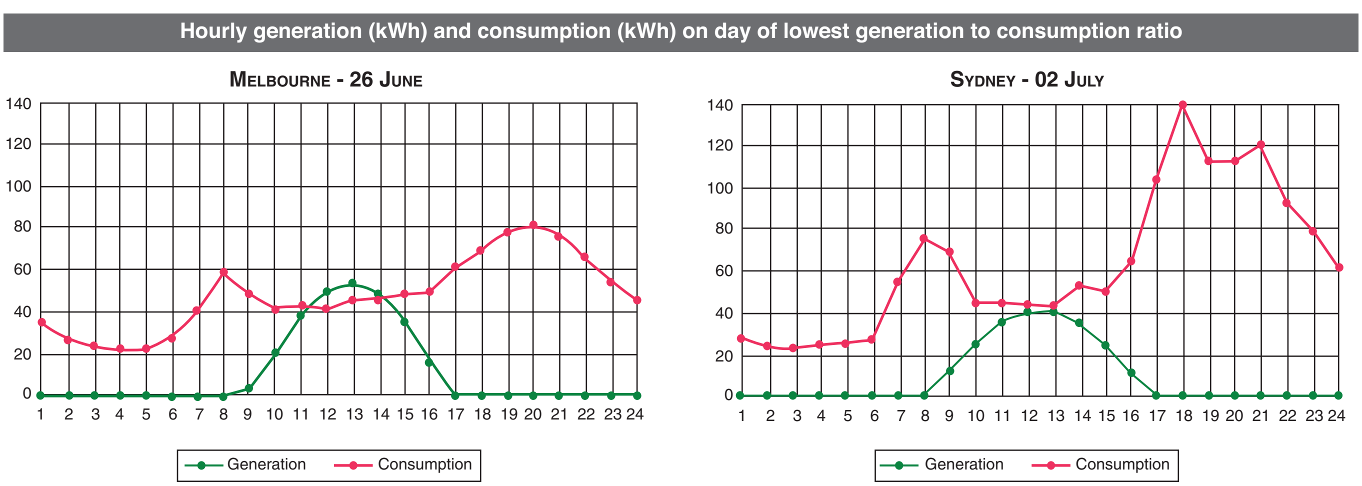


Figure 9: Comparison hourly generation and consumption on day of lowest generation to consumption ratio for Melbourne and Sydney

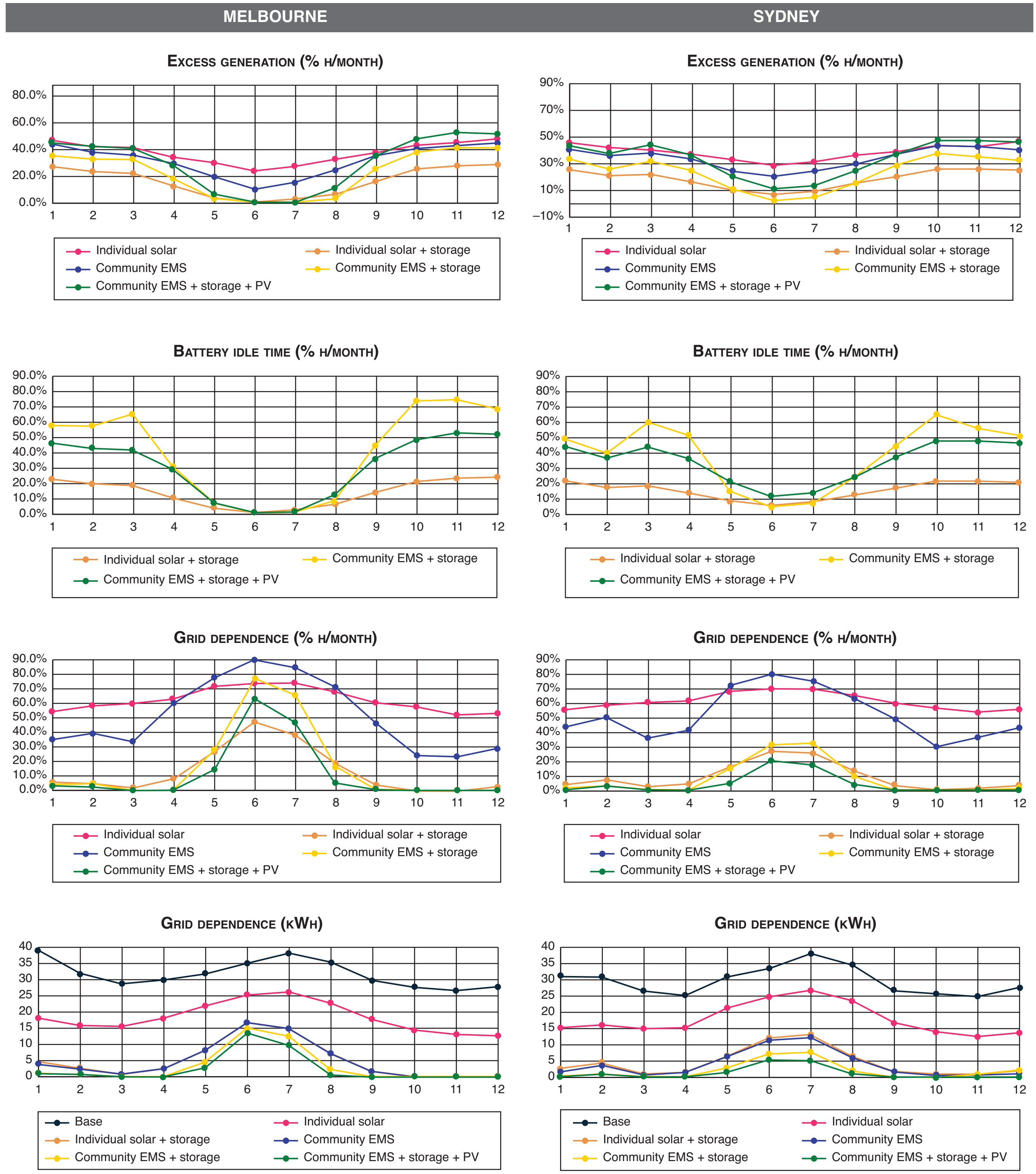


Figure 10: Comparison of excess generation, battery idle time and grid dependence (in hours and kWh) for Melbourne and Sydney

Notwithstanding the mild conditions during winter, even in the best of cases, the development cannot eliminate completely its grid dependence during the winter season when consumption is at its highest while generation is at its lowest. Again, despite the extreme heat registered during the summer, grid independence is possible because of the improved generation capacity due to seasonal characteristics.

The possibilities of adding PV modules is limited by space constraints on both built structures and open areas and increasing storage beyond a certain point does not render major gains. The benefit to investment on storage curve flattens very quickly after the optimal point. Storage produces a large benefit during the milder weather months, allowing grid independence for approximately seven months per year for Melbourne and five months for Sydney, but does not provide much additional value during the months of more extreme weather when patterns of consumption and generation are at its more pronounced mismatch.

Even though Melbourne has a greater peak during the winter season, Sydney tends to be more "peaky" - in much smaller but more frequent peaks - during the whole year, thus, with the same generation and storage resources, Melbourne achieves grid independence during more months of the year than Sydney.

Figure 11 summarises on monthly averages the number of hours per day that there is demand from the grid. The apparent anomaly observed between the lower values of the Individual + Storage scenario and the Community EMS scenario is due to the fact that the first one averages 81 individual dwellings while the latter considers the hourly requirement of the community as a whole. The diversity factor which is averaged in the first case scenario –i.e. number of hours per dwelling regardless of time of use- is actually reflected in the EMS scenario –i.e. different times of use become meaningful as values- thus increasing the profile of the curve.

Although the solar exposure of Melbourne and Sydney is quite different, installing just PV panels on each dwelling produces a very similar result from the perspective of grid independence, due to the fact that, regardless of the amount of electricity generated, the hours of generation are roughly the same. At individual level –i.e. separate systems on each dwelling- the addition of storage capacity starts to differentiate outcomes between Melbourne and Sydney. During the peak of winter, on averages, Melbourne depends on the grid 47% of the time while Sydney drops its reliance to 27% of the time.

When storage is added at a communal level and managed by a central energy management system the difference between the southern and northern cities exacerbates; Melbourne with its lower generation capacity during the winter season peaks at 18 hours per day dependence on the grid while Sydney does so at 8 hours per day. Adding communal generation drops Melbourne's hourly dependence to just over 14 hours and Sydney's to just under 5.

When PV panels and storage are installed on individual dwellings, the average time batteries are idle in Melbourne is less than the average time that supply is required from the grid, but in Sydney both average times are roughly the same. With the addition of storage at a community level, the battery idle time becomes a multiple of the time of grid dependence, thus reflecting the generally excess capacity that is required to cater for the peaks. The same that happens with storage happens with excess generation when communal PV panels are added to the generating capacity of the individual systems.

Besides the 1.122 MWh storage capacity installed across all individual dwellings, the community has the possibility of installing further storage in the form of a communal battery to make use of the excess generation provided by the individual PV systems. This communal battery provides the greatest benefit -i.e. greatest reduction in grid dependency per kWh installed- to around 0.5 MWh capacity; after that, there is a reduction in the benefit ratio, especially for Sydney conditions. Even though Sydney does reach grid independence with around 9.5 MWh of communal storage, compared to 12.5 MWh for Melbourne, the storage benefits are more slowly realised (Figure 12(a)); Sydney is 60% less dependent on the grid than Melbourne when communal storage is 0.5 MWh, but reaches independence with only 24% less storage. In general, investment on storage has a greater effect in Melbourne than in Sydney.

Besides the 1898 PV panels installed on the individual dwellings, the community also has the possibility of installing further generation in the form of communal PV modules to provide shelter for footpaths and/or parking, roofs for other common structures, etc. Again, Sydney has a better starting point but Melbourne makes better use of the investment on additional generation capacity. For Sydney, the benefit curve starts flattening at around 400 additional modules, while for Melbourne the curve, although slightly less steep than Sydney's, does not flatten until close to 2000 additional modules (Figure 12(b)).

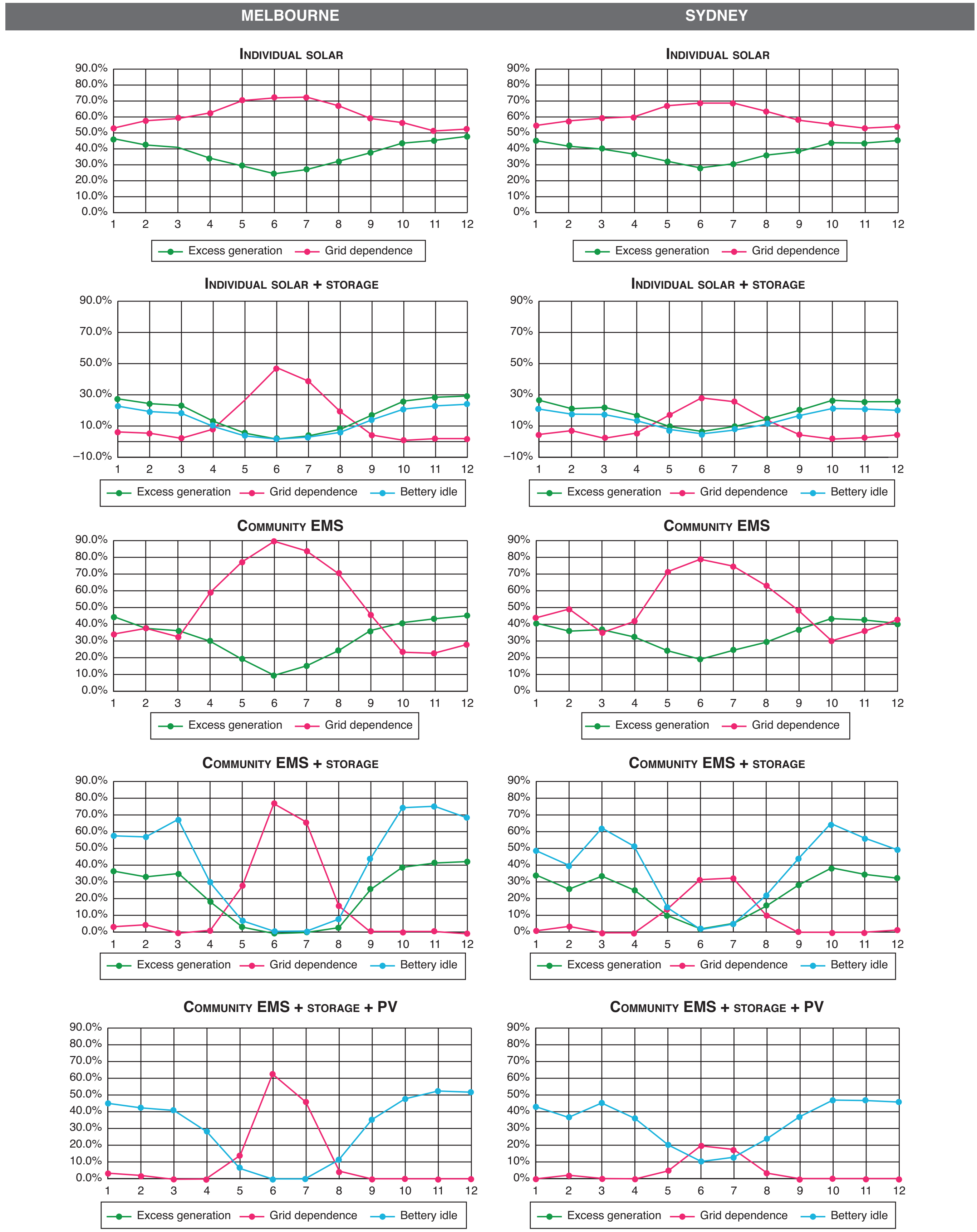
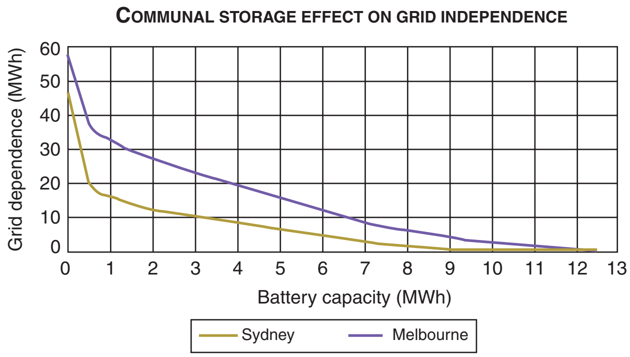


Figure 11: Comparison of hours of excess generation, battery idle time and hours of grid dependence for scenarios in Melbourne and Sydney



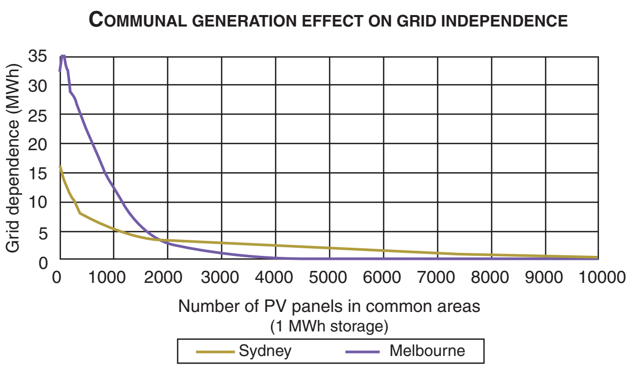


Figure 12: (a) upper and (b) lower, showing effect of additional battery and PV generation on grid dependence.

The peak in the Melbourne curve -at just below 100 PV panels- is due to the fact that, on aggregate, the consumption of the communal system is greater than its contribution to useful generation: during the warmer months with longer days, the additional electricity production just adds to the excess generation, while during the winter with shorter days, the production does not compensate for the additional consumption at a time when the system needs to cater for colder and shorter days.

The increase of storage has a larger effect in Sydney than in Melbourne while the increase of generation capacity –i.e. solar modules- has a larger effect in Melbourne. This is due to the fact that Sydney, because of climatic conditions, has larger generation with the same number of solar modules.

5. Conclusions

This modelling has focussed on one year, i.e. 2014, of real-world consumption and weather data which means the ratios will change when studying other years. However, the results are significant given that they represent real conditions, and continuing work is looking at other years, as detailed consumption and weather data becomes available.

In general, the climatic conditions in Melbourne or Sydney make it difficult to be grid independent because the highest consumption generally occurs at the lowest generation time.

Efficiency of the dwellings themselves is a crucial determinant in achieving further grid independence as it allows 'shaving' the consumption peaks of winter. More thermally efficient building envelopes to reduce heating requirements and more efficient lighting to reduce the load of providing for longer darker periods during which there is no generation. Demand side management is the other critical element to reducing the consumption peaks that make it difficult for RE systems to supply for independence from the traditional grid.

Given that the largest improvement in grid independence results from the installation of solar systems with storage on each individual dwelling, the implementation of a CREN does not seem particularly attractive taking into consideration the considerable legal and onerous requirements that present rules and regulations impose on this type of initiatives. The advantages of the implementation of a CREN rest more on financial viability, reliability and security of supply, improved interaction with the larger electricity distribution network, and management of the whole system rather than on absolute values of energy demand reduction from the traditional grid.

Even though Melbourne has more extreme winter averages, at a granular level, Sydney's ratio of PV generation to consumption can be lower than that of Melbourne on any given winter day. Thus, the systems, albeit more over specified in Sydney than in Melbourne for most of the year, do not differ much in required capacity when it comes to catering for extreme demand.

Theoretically, it is possible to go off grid by providing extremely large amounts of electricity storage, but practically the cost and implied waste of assets and resources of such method of implementation do not favour the viability of such approach. Thus, if independence from the grid is the goal, demand side management or demand response should be the initial focus of any community initiative.

Designing a system to cater for the peaks of a CREN -as they exist with current building methods and user behaviour patterns- replicates the 'gold plating' problem for which the traditional grid has been criticised. It implies vast deployment of resources that will be used only to a small fraction of their capacity.

Acknowledgements

We would like to thank Fiona Orton from AGL for providing the consumption data and Paolo Bevilacqua from Frasers Property for the urban development data required for this research.

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