Beyond the Death Spiral

Transitioning to Renewable Energy in Western Australia

William Grace

Australian Urban Design Research Centre
University of Western Australia
PO Box 2729
Cloisters Square
Perth WA 6850
Australia
T: +61 8 6318 6200
E: bill.grace@uwa.edu.au

Abstract

Model based projections for the rapid uptake of rooftop solar photovoltaics in Western Australia indicate that private capacity will be so large that the centralised network based electricity system will become disrupted in the 2020s. By 2050 private systems may produce around 85- 90% of projected electricity demands. In the interim period it may be more economically viable to avoid introducing large scale renewable energy to the network while planning for a completely renewable system by 2050 when rooftop solar approaches saturation levels.

By 2050 it is projected that only around 2,250 MW of large scale renewable energy will be needed to complement private solar PV, optimally in the form of wind energy, or a combination of wind and wave energy. In order to avoid very large storages it will be necessary to retain fast response thermal generation, most likely using state of the art open cycle gas turbines fuelled by renewable sources such as biogas from organic wastes.

The network will likely require around 32,000 MWh of energy storage to complement the private storage by 2050, with pumped hydro utilising Perth's water supply dams, a potential source.

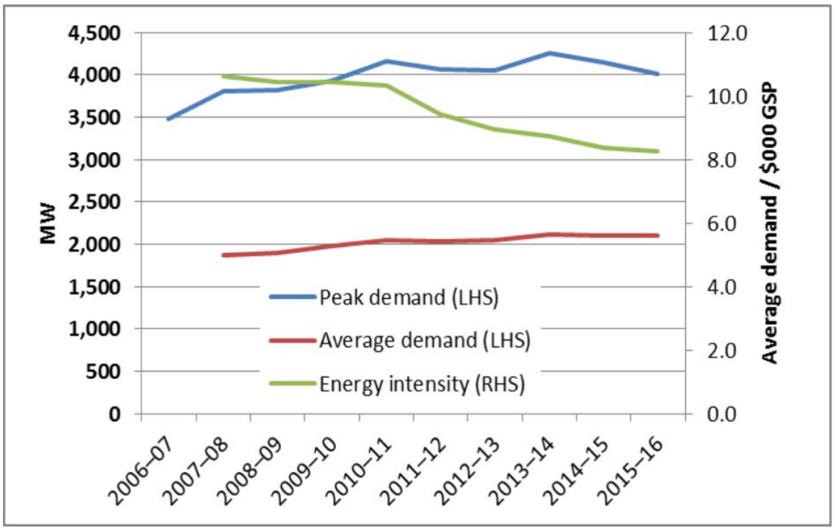
Keywords

Solar, electricity, energy, battery, storage, wind, wave, network

Introduction

In a previous study (Grace, 2015) I described the use of a system dynamics model to explore the impact of private solar PV and battery storage on the electricity network in Western Australia, known as the South West Interconnected System (SWIS). They key findings of that work were that falling costs of solar PV systems will drive exponential growth that will eventually disrupt base-load generation. In this article I examine the broader implications of these findings in respect of transitioning the network to 100% renewable energy.

The SWIS serves Perth, the capital city of Western Australia and the south west which is the most populous region of the state. Both peak and annual demand (Figure 1) has plateaued in recent years(Australian Energy Market Operator, 2016) due to a combination of factors including the uptake of private solar PV, energy efficiency measures and slower population growth. Changes in the nature of the economy (particularly decline in manufacturing have seen a decline in energy intensity, i.e. electricity demand per unit of Gross State Product (GSP).

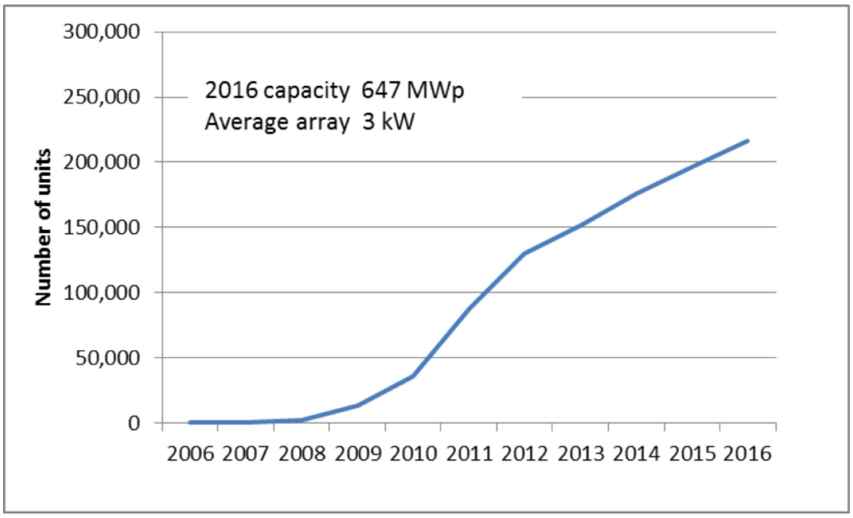


Source: Australian Energy Market Operator (AEMO)[1] and author's calculations

Figure 1 Electricity demand on the SWIS

The SWIS remains very much a fossil fuel dominated network, with coal providing 30% of capacity, gas a further 25% and hyrid gas / diesel peaking plants another 28%. In 2014-15 only 3% of the energy generated came from renewable sources, mainly wind which accounted for 94% of renewable generation.

Over the same period there has been a rapid growth in the uptake of private solar installations in the state, mirroring the situation in other states of Australia and across the world more broadly. Western Australia currently has some 650 MW of rooftop solar (Figure 2). In the area served by the SWIS some 23% of customers have rooftop PV. The average size of systems is 2.5 kW, although new installations in 2015-16 averaged 4.5 kW. Since 2010-11, the average annual growth rate of installations has been 25% per annum, and system sizes have grown at 19% per annum.



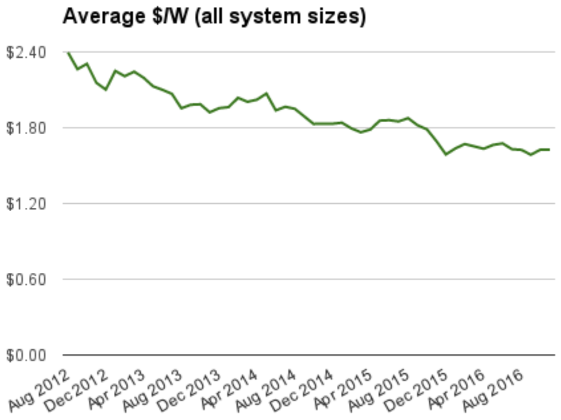
Source: Clean Energy Regulator[2]

Figure 2 Rooftop solar PV installations in Western Australia

[1] https://www.aemo.com.au/Electricity/Wholesale-Electricity-Market-WEM/Planning-and-forecasting/WEM-Electricity-Statement-of-Opportunities

[2] http://www.cleanenergyregulator.gov.au/RET/Forms-and-resources/Postcode-data-for-small-scale-installations

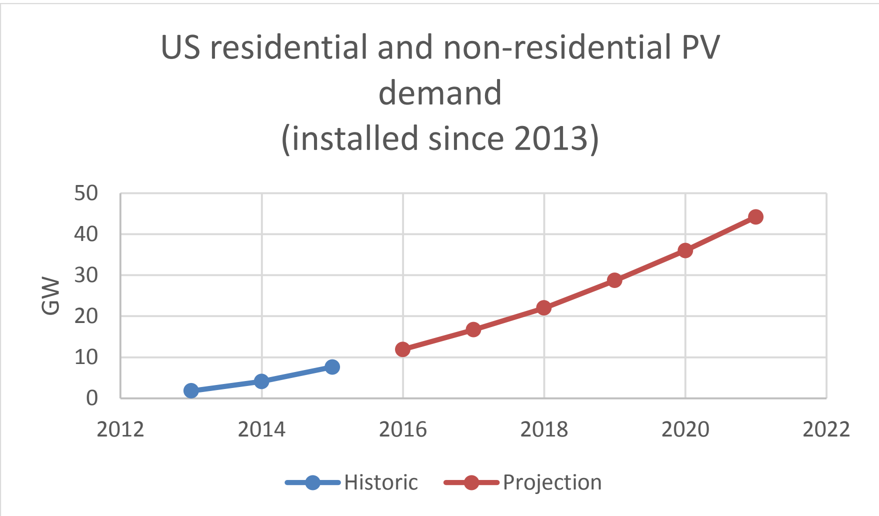
The major factor in the growth of private solar PV is the unit cost, which has decreased by 40% over the period from 2012 to 2016 (Figure 3). These costs include the benefit of Australia's Renewable Energy Target under which small scale solar PV systems receive a rebate based on an estimate of the amount of generation. A 1 kW system in the SWIS area receives small scale technology certificates (STCs) which presently realise a discount of about $775. The majority of these system are on residential rooftops, as the take-up in commercial premises has been limited to date, partly impeded by restrictions placed on connections by the government owned network operator, Western Power [3].



Source: Solar Choice [4]

Figure 3 Unit cost of solar PV in Australia

The rapid growth of rooftop solar is a worldwide phenomenon. In their Q2/Q3 2016 Solar Industry Update (Feldman, 2016), the US Department of Energy provide an insight into the growth of rooftop solar PV in the US (Figure 4). These figures exclude utility scale solar PV and represent annual growth rates of 50% per annum for the period 2013-15 and 30% per annum for the projected period.



Source: U.S. Department of Energy

Figure 4 U.S. Solar PV installations

[3] http://reneweconomy.com.au/regulations-cause-dead-spot-in-wa-solar-market-91167/
[4] https://www.solarchoice.net.au/blog/news/residential-solar-pv-system-prices-december-2016

Objectives of the study

Findings from the previous study identified that by the early 2020's the so-called duck curve will be in play on the SWIS (Figure 5), i.e. there could be an intermittent over-generation problem when minimum network loads fall below the normal operating capacity of baseload coal generation, which is intended to run consistently and cannot be readily cycled down and up in a matter of hours. Steep ramping of generation is required in the hours of declining solar generation. A similar situation has been identified by the California Independent System Operator[5].

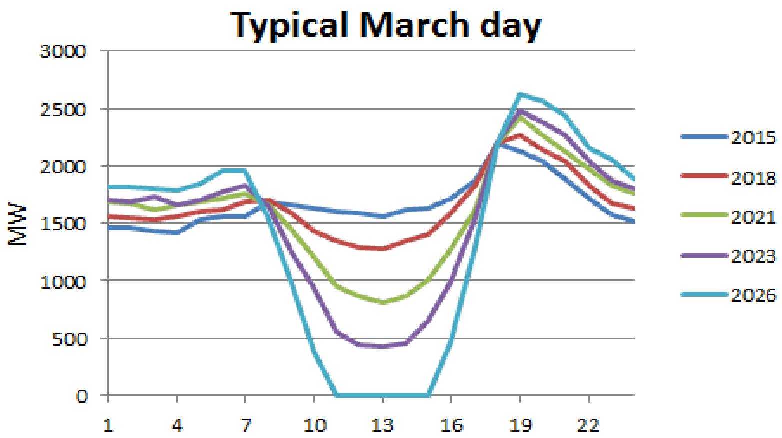


Figure 5 The SWIS duck curve

This raises the question of both the scale and role of legacy networks in the future given:

- the likely ongoing cost reductions in solar PV and battery storage; and
- the necessity of eliminating fossil fuel based generation by mid-century.

The work presented here uses projections of the take-up of private solar and storage to explore what the SWIS (and by analogy all similar centralised networks) might look like by 2050, and what policies should be in place to progress an orderly transition.

The results reported here are derived from 2 separate system dynamics models, as described below.

Models

A monthly time step model described in the previous paper[6], uses arrays to model the hourly behaviour of a typical day in each month. It has been modified for this study to run from 2015 until 2050, i.e. 420 months. This model establishes electricity demand and the likely take-up of solar PV and storage by households and businesses.

A companion hourly time step model that simulates each hour of the year, again by assuming a typical day for each month, is used to model network storage for both private generation and that of large scale renewable energy generation that will be added to the system as it transitions away from fossil fuels.

Both models use Version 6.3 of the Vensim Professional software.

The monthly model determines the electricity demand separately arising from:

[5] http://www.caiso.com/documents/flexibleresourceshelprenewables_fastfacts.pdf

[6] A full explanation of the model structure, together with its documentation, is included in a detailed report on the research at https://www.audrc.org/exploring-the-death-spiral/

- residential houses; and
- commercial and industrial facilities.

The existing residential demand and commercial demand profiles have been determined from historical half hourly reports of total network load, and presentations of the previous independent market operator (IMO WA) on residential and commercial loads.

The model calculates the contribution of household scale solar energy generation, with and without energy storage. The model calculates the payback period for a household arising from:

- avoided electricity imports from the network at the residential tariff; plus
- electricity exports to the network at the residential feed-in tariff (renewable energy buyback scheme); and
- the installed cost of solar energy and battery storage.

The unit cost of solar PV is modelled as a stock with an initial value reflecting present unit costs (A$2,200 /kW) which is the approximate installed cost of systems in Australia presently, excluding the benefit of the small scale technology certificates (STCs). The model assumes that the unit cost transitions to a final unit cost of A$1,000 /kW (Figure 6).

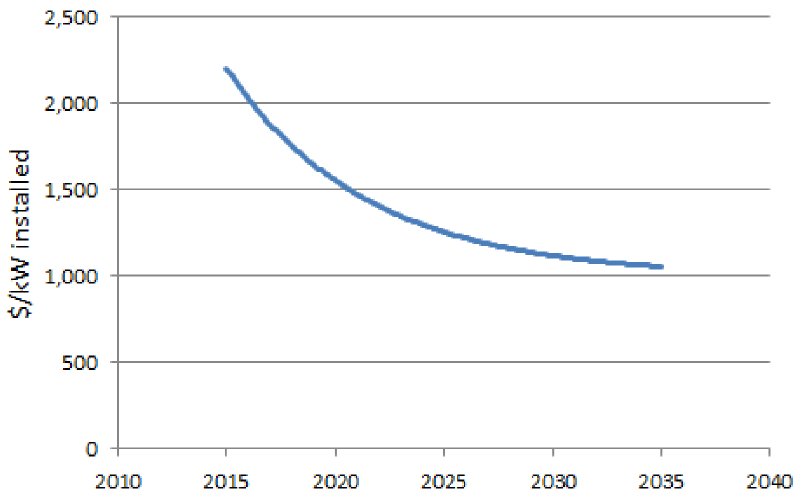


Figure 6 Solar PV cost curve

The model sets an optimum storage capacity based on the capacity of the solar array, which avoids multiple combinations of solar capacity and storage capacity. The model calculates the additional benefit to the householder from adding storage to their solar array. It is assumed that storage operates simply on the basis that:

- solar generation in excess of demand is stored (up to the limit of the storage capacity);
- the storage discharges to meet demand that cannot be met by solar generation; and
- remaining demand is met by the SWIS network.

The incentive to add solar PV and storage is determined by a payback period (Figure 7) calculated from the benefits noted above and the unit cost of solar storage. The latter assumes that the present storage costs of approximately $1,000 / kWh will drop to around $200 / kWh (Climate Council of Australia, 2015) (Figure 8).

The model structure for commercial solar is identical to the residential model in all respects, except for the initial conditions. The model assumes that at the outset there is no commercial solar or storage. It is assumed that a maximum of 60% of residential dwellings could accommodate solar PV and storage, and 50% of business premises. A maximum array of 7.2 kW is assumed for houses and 150 kW for businesses.

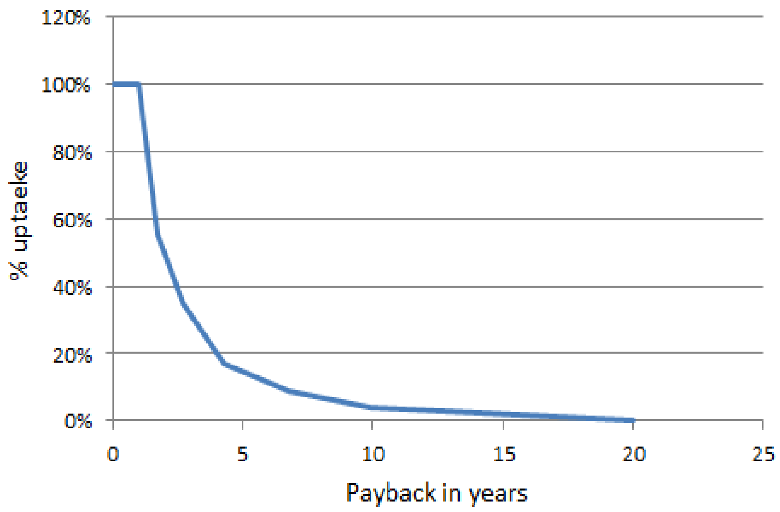


Figure 7 Uptake of solar and storage based on payback period

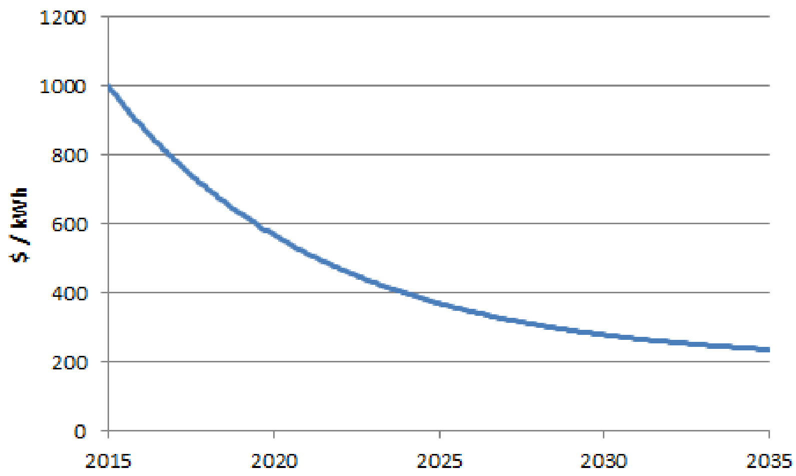


Figure 8 Cost curve for household and commercial scale battery storage

Electricity demand is based on assumptions of the market operator and manifests as a doubling of total demand over the period 2015 to 2050 (average annual growth of 2% per annum).

The model incorporates changes in tariff over the simulation period by assessing the operating costs of the network as it is affected by private solar / storage. Take-up is however dominated by the falling unit cost of those technologies rather than increases in tariff, although these could be very significant, as previously reported.

However the take-up of private battery storage will be very much influenced by tariffs. The payback period for private battery storage is dependent on the relative costs of imported and exported energy. Currently in Western Australia (for most customers) the former is around three times the latter (the solar feed-in-tariff), meaning there is a strong business case for storing energy for later use, thus reducing the amount of more expensive imported energy. If however, the solar feed-in-tariff is the same as the import tariff (so-called net metering) there is no business case for private storage. Accordingly future policy changes will have a large impact on the take-up of private storage which is still in its infancy.

Various tariff policy scenarios that affect the likely take-up rates of solar PV and storage were simulated including assuming the feed-in-tariff remains as it is, doubling and tripling the feed-in-tariff. This analysis shows that to have a major influence on the take-up of private storage, the feed-in-tariff would need to be tripled. Given the cost of such a measure to a network that is already operating with revenues below cost, there is little likelihood of this occurring. Accordingly, the following assumes that private storage take-up occurs in line with the model projections using the existing feed-in-tariff, escalating network tariffs and assumed solar PV and storage cost reductions referred to above.

Monthly modelling results

The result of this modelling (Figure 9) indicates that by 2050:

- Nearly 60% of houses and 50% of businesses have onsite solar PV systems, with output of 6,000 MW and 15,000 MW respectively; and
- Nearly 50% of houses and 45% of businesses have onsite energy storage systems, with capacity of 10,000 MWh and 20,000 MWh respectively

Although the addition of storage lags initially, it increases significantly after 2025 when unit costs are starting to fall significantly. However even at 2050 private storage in aggregate is still only 1.5 hours of nameplate solar capacity.

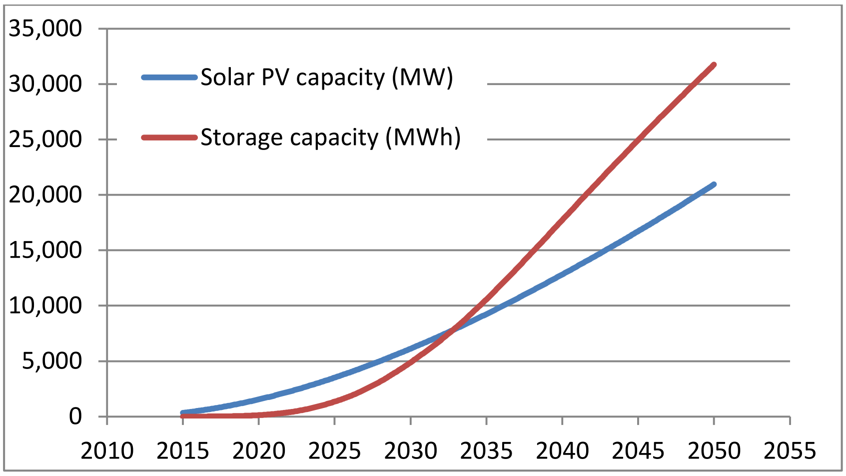


Figure 9 Simulated take-up of private solar PV and storage

By 2050, total electricity demand is projected to be 37,000 GWh per annum. Rooftop solar PV in Western Australia has a capacity factor of around 0.183, meaning that 20,000 MW of private solar is capable of generating some 32,000 GWh per annum, i.e. 85% of total electricity demand. Although counter-intuitive at first glance, these projections are based on modelling the rational behaviour of electricity users who respond to their own cost-benefit assessments of the options, i.e. purchasing electricity from the network versus a capital investment in solar PV that has virtually no operating costs and a payback period of less than 5 years (within a decade). Unless the cost projections of solar PV turn out to be wildly optimistic, or the cost of network generated electricity reduces significantly, it is difficult to come to any other conclusion than, in the future, most energy will be generated onsite by solar PV. Although it could be argued that network scale solar or wind energy could eventually be cheaper than small scale systems on a per MW basis, the cost of distributing it will always be a necessary on-cost that is avoided by onsite generation.

Of course to realise the private solar scenario described above, all privately generated power would have to be utilised. In the previous study, I assumed that when private solar energy generation exceeded total demand in the middle of the day (commencing in the early 2020s) private solar PV generation would be curtailed by the network operator (assuming it is possible to do so), because there is currently no network storage capacity. However if this was to occur, zero marginal cost, emission free power would be substituted by highly polluting, expensive fossil fuel based generation, simply to enable the network to operate as it has historically. This would be a perverse outcome.

This conclusion has very significant implications for policy formulation. Much work is going on in Australia (Blakers, 2017)and elsewhere to identify how the national network (National Electricity Market) and the local SWIS can transition away from fossil fuels. However most of these studies assume that the network will be of similar scale, and operate in a similar way to the current situation.

The reality is that the future network will be much smaller and structured to accommodate large scale renewables, but only to complement onsite generation. Its major role will be to store energy to balance generation with demand, which requires storage well beyond the 1.5 hours likely to be procured privately.

The second part of this study seeks to identify how this new network might develop over time.

Renewable energy targets

Various dates for the transition to a fully renewable energy electricity system have been suggested in Australia, and in Western Australia. Although the national government has made commitments under the Paris accord for reductions in greenhouse gas emissions in aggregate, these commitments only require Australia to reduce emissions by 26-28 per cent (on 2005 levels) by 2030. Australia is the fifteenth largest emitter of greenhouse gases in the world (Climate Change Authority, 2015). There is currently no meaningful approach to reducing economy wide emissions since the current government abolished Australia's emission trading scheme in July 2014. However the Renewable Energy Target (RET) has been in place nationally since 2001. Under this scheme some 20 per cent or 41,000GWh electricity was to be generated by renewable sources by 2020. The current government has recently reduced this to 33,000 GWh by 2020.

The current national opposition party has committed to 45% emissions reduction on 2005 levels by 2030, and pledged to ensure that 50% of Australia's electricity is sourced from renewable energy by then. The Australian Greens policy is to increase the RET to achieve 90% renewables by 2030.

The modelling results set out above provide some insights into the selection of an appropriate target. Three scenarios have been examined for achieving 100% renewable energy in the SWIS area: by 2030, 2040 and 2050. This is simply done by calculating the renewable energy that would have to be generated at utility scale to complement private solar generation. The result of these calculations is set out in Figures 10 a) to c).

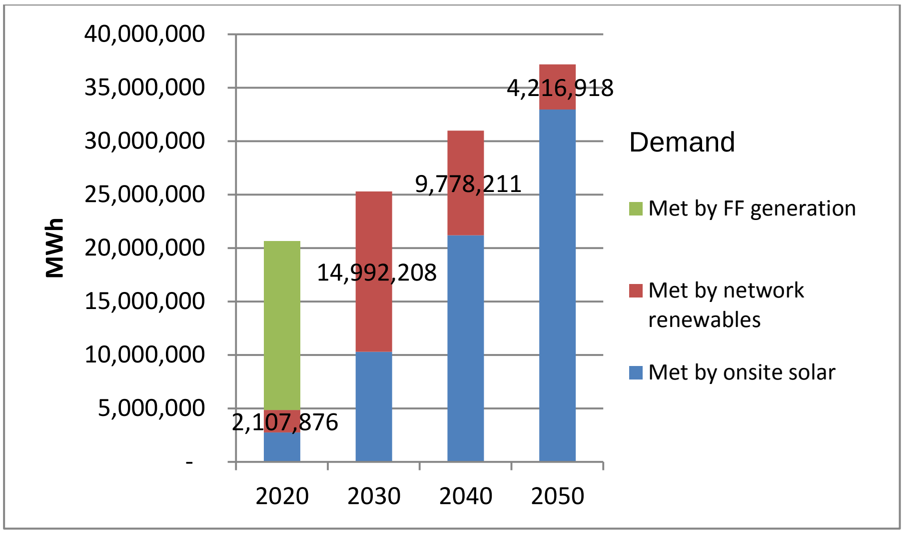


Figure 10a) Generation mix to achieve 100% renewable energy by 2030

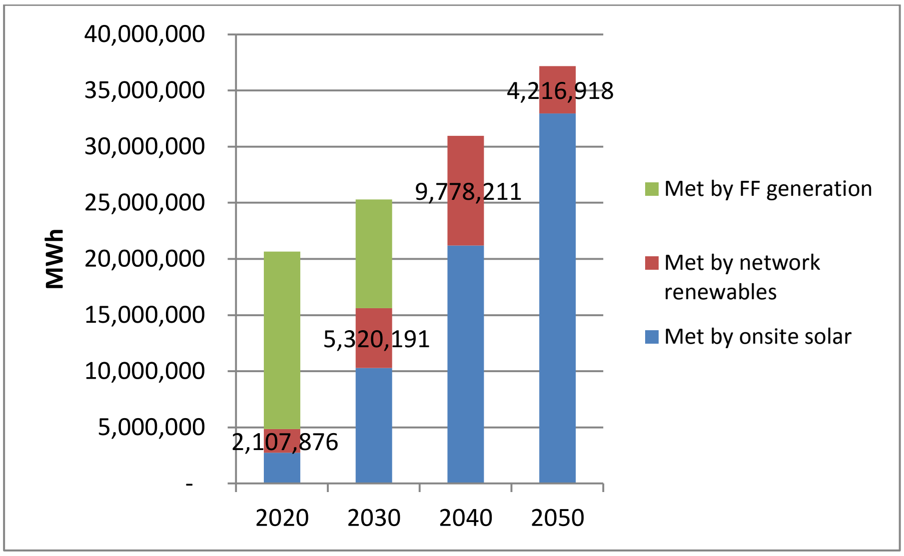


Figure 10b) Generation mix to achieve 100% renewable energy by 2040

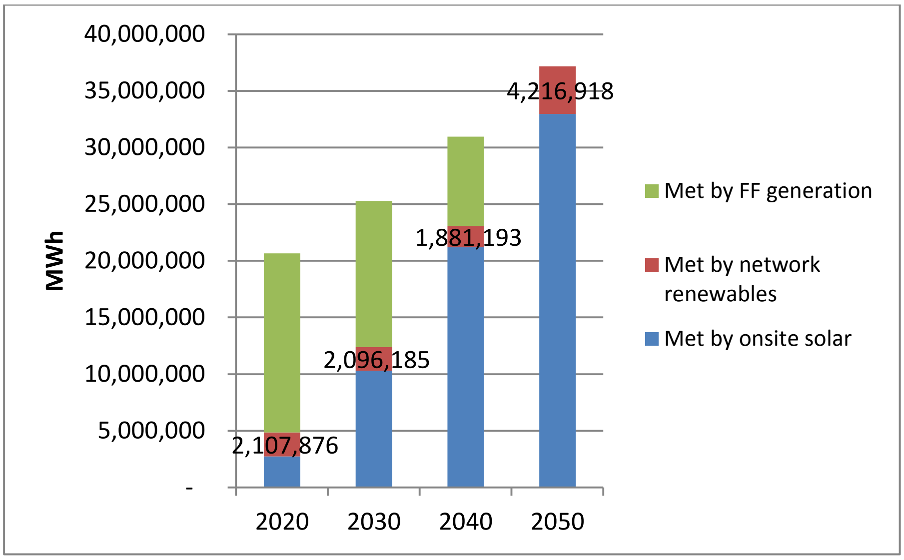


Figure 10c) Generation mix to achieve 100% renewable energy by 2050

All scenarios assume that network renewables increase to achieve the RET target of 23.5% by 2020, and then fill the gap between the renewable target and private solar generation thereafter. Aggregate electricity demand increases beyond 2050 would need to be shared in similar proportions between network renewables and onsite generation under the modelling reported here, i.e. that private solar has reached near saturation by 2050 as a fraction of housing and business stock.

As Figures 10a) and b) indicate, an early transition to network renewables may be problematical in that the required capacity first increases and then decreases over time as the cost-benefit of private onsite solar PV improves (see Figure 9) and take-up approaches saturation. As the design life of wind turbines is 20-30 years and for solar farms is 25 years, it will not be commercially viable to annually decrease the generation output of renewable power stations in this way. If the real world uptake of private solar reflects the projections here, setting a target of 2050 appears to be the most practical and economical way of introducing large scale renewable energy to the SWIS, while eliminating fossil fuel based generation in a gradual and orderly way.

This scenario would require renewable generation on the SWIS to increase from the currently modest 500 GWh pa to 2,100 GWh pa by 2020 and then double over the following 30 years. Such a scenario would also benefit from the likely decrease in unit cost of large scale renewable energy systems over that time period. However the major focus for the network will be to store energy rather than generate it.

The Future SWIS

An hourly model that represents a typical day in each month of the year was used to examine in more detail the scenario identified in Figure 10c) above, i.e the situation at 2020, 2030, 2040 and on achievement of a fully renewable energy system by 2050.

The model calculates the amount of energy generated by private solar systems with battery storage and accordingly the residual load on the local network. When the aggregate amount of solar PV generation exceeds demand, energy is exported to the network, where it is seen as a negative load. According to the results reported above this situation will likely commence in the early 2020s. The model simulates the diurnal network demand pattern across the year, and matches generation and network energy storage at either (or both of) the local substation scale or transmission scale.

The existing residential demand and commercial demand profiles have been determined from historical half hourly reports of total network load, and presentations of the system operator on residential and commercial loads (Australian Energy Market Operator, 2016). The annual residential demand has been derived from the reported network loads, modified to include the demand met by private solar. Generation patterns for household solar energy are based on analysis of data from the network manager Western Power (Jones, 2012). Generation patterns and capacity factors for wind energy and large scale solar energy are derived from actual data from existing facilities on the SWIS (Rose, 2016)[7], and wave energy data for Western Australia derived from (Hughes & Heap, 2010). Demand and generation patterns are read into the model via Excel lookup functions.

A screen shot of the network generation and storage element of the model is shown in Attachment A.

[7] Courtesy of Sustainable Energy Now's SIREN model http://www.sen.asn.au/

By 2020

By 2020 it is projected that there is 1,550 MW of private solar PV generating some 2,500 GWh of electricity. The largest single renewable energy facility on the SWIS presently is the Collgar wind farm at 206 MW. This facility operates at a capacity factor of 0.38, generating some 686 GWh pa. Adding a further 1,400 GWh to the network by 2020 is therefore not a major impediment. Renewable energy in the form of onsite solar and network wind generation are meeting about 22% of network demands.

Figures 11a) illustrates the impact that private solar exports (Figure 11b) have on network loads. Although there is 135 MWh of private storage, this is insufficient to affect electricity demand at the local substation scale. However at this stage baseload thermal generation potentially becomes disrupted as minimum loads approach 1,000 MW in Autumn.

Figures 11 c)-e) show how total demand is met on an annual basis and for typical January and July days.

By 2030

By 2030 it is projected that there is 6,000 MW of private solar generating nearly 10,000 GWh of electricity (Figures 12b), now having a significant impact on network loads (Figure 12a). There is also nearly 5,000 MWh of private storage, although this is insufficient to avoid net exports of power to the network in Autumn and Spring when demands are lowest (Figure 12a).

A small amount of additional renewable energy (now 750 MW of wind) is required at network scale to achieve nearly 50% of demand from renewable energy. Network demand drops to zero in the middle of the day in most months of the year (Figure 12a) and very steep ramping of the thermal network occurs, meaning that baseload coal generation will need to be eliminated well before 2030. The system will become more dependent on fast response open cycle gas turbines and energy storage during the 2020s.

Figures 12 c)-e) show how total demand is met on an annual basis and for typical January and July days. In this scenario storage at the network scale required to absorb the net exports from private solar, is avoided by curtailing a minor amount of wind energy.

By 2040

By 2040 it is projected that there may be 13,000 MW of private solar capacity generating some 20,500 GWh of electricity (Figure 13b). This is likely to be supplemented with nearly 18,000 MWh of private storage which will play a more significant role in balancing supply and demand behind the meter. However this is still insufficient storage to avoid large exports to the network (Figure 13a).

No additional renewable energy is required at network scale, as onsite solar and 750 MW wind is sufficient to reach nearly 75% of demand from renewable energy. Fast response thermal generation is still required throughout the year (Figure 13c-e), although is sparsely used in the summer months.

About 22,000 MWh of network storage is now required to absorb the net exports from private solar, and to absorb wind generation without curtailment (Figure 13f). Storage is effective in meeting network loads in all but the winter months.

At this stage private solar and storage is providing for about 65% of demand, wind energy for 8% of demand and the balance (27%) by thermal generation.

By 2050

Private solar PV systems are now nearing saturation in the system at about 60% penetration in residential premises and 40% of businesses. Further demand growth beyond 2050 will be met pro-rata by onsite and network generation. Accordingly the 2050 scenario provides a picture of how the system may operate into the future.

By then the total capacity of solar generation is about 20,000 MW, and is accompanied by 32,000 MWh of private storage (Figure 14b). However this is insufficient to avoid very large exports of solar energy to the network in the middle of the day (Figure 14a), exceeding system demand in the summer months.

Wind energy is increased during the previous decade and its capacity now is 2,250 MW. The implications of this level of solar and wind generation is significant for the network (Figure 14c-e). Extremely large storages of around 32,000 MWh are required to meet demand and avoid excessive over-generation. Even then it will be necessary to retain fast response thermal generation to avoid massive storages. In this scenario, 2,500 MW of thermal generation is retained, although it is only operational in the winter / early spring and generates only 1,600 GWh per year (less than 5% of demand). In order to maintain storages at economically viable levels, the amount of wind energy is somewhat greater than necessary for energy balance, leading to about 4,000 GWh of curtailment of wind energy in the early and latter parts of the year. At such high penetration of renewables the challenge will be to optimise the quantity of rapid response thermal generation and network scale storage.

Assuming that the thermal generation can be supplied by renewable sources, this scenario represents a fully fossil free electricity system served by 90% private solar and storage, 6% by large scale wind and 4% by thermal generation.

Technologies

Large scale renewable energy

In the foregoing it is assumed that wind will be the future source of renewable energy at network scale. Various combinations of wind, large scale solar and wave energy were tested using the model.

Figure 15 illustrates the assumed capacity factors for each resource across the year, depicted as a fraction of their annual hourly average. This illustrates that while performance of both solar and wind decline during the middle months of the year, wave energy is at its highest.

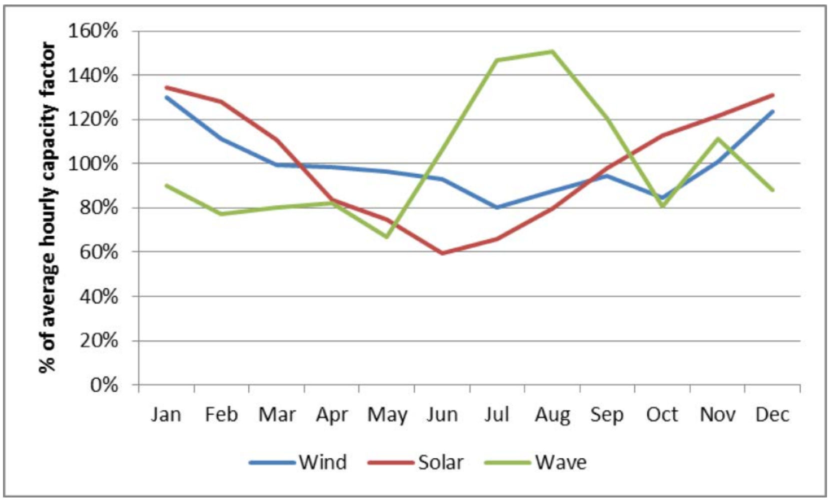


Figure 15 Capacity factors of renewable energy sources

However the diurnal performance of each source is also important. In order to understand the impact of each it is useful to see the performance of each source at the most important time, when residual network demands are high at the end of the day (i.e. when the influence of onsite solar is at its lowest). Figures 16a) and b) illustrate the capacity factors of wind, solar and wave for typical January and July afternoons and evenings in 2050[8]. In the summertime evenings, wind energy is increasing and operating at about 150% of its average annual performance, while wave energy is operating at about its average annual level. Although at its most powerful early in the day, solar is declining rapidly during this period. In the wintertime, wind energy is relatively constant across the day but only operating at about 80% of its annual potential. On the other hand wave is operating at about 150% of its average annual level.

For these reasons, meeting the residual network loads using large scale solar PV requires double the amount of storage as is required for a wind resource that is available throughout the day and night. However wave energy could be a valuable complement to wind energy, as its constancy is very high and its performance during the winter is superior to other sources (Hughes & Heap, 2010).

Other sources that could be economically feasible by 2050 such as concentrated solar, which can potentially incorporate storage, have not been considered in this study.

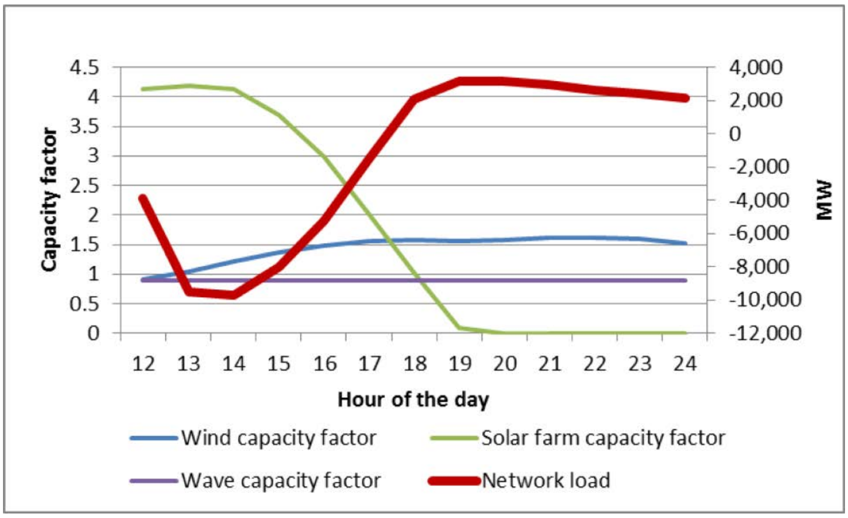


Figure 16a) 2050 January day - network load vs capacity factors of renewable energy sources

[8] In the absence of more detailed hourly data, capacity factors for wave energy have been assumed to be constant across the day of each month, but vary from month to month.

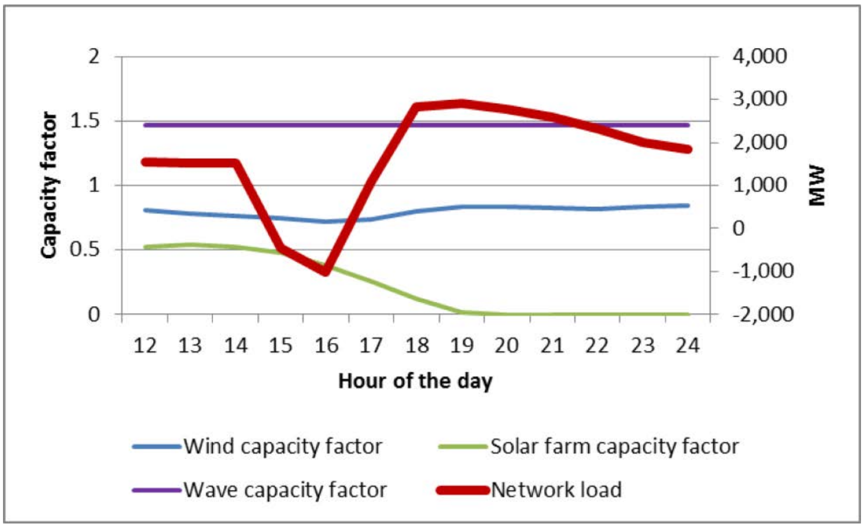


Figure 16b) 2050 July day - network load vs capacity factors of renewable energy sources

Thermal generation

It is assumed here that by 2050 the 2,500 MW of thermal generation is provided by open cycle gas turbines, which are prevalent as peaking plants in the current SWIS, fuelled by natural gas. A recent study (Rose, 2016) proposes state of the art 'aero-derivative' turbines with the capability to run on bio-diesel derived from oil mallee. Another promising source is biogas derived from anaerobic digestion of organic wastes. By 2050 Perth households will be producing around 4.5m tonnes of organic wastes(Zhang, Su, Baeyens, & Tan, 2014) , which can produce enough biogas to generate around 1,000 GWh of electricity, which is about 60% of the projected thermal energy requirement of the SWIS. If organic wastes from wastewater treatment plants and animal manure are added, it is likely that biogas could provide most or all of the feedstock necessary for thermal generation, simultaneously reducing greenhouse gas emissions from the natural decomposition of organics in the environment.

Network energy storage

Storage at the network scale could potentially be pumped hydro as assumed in a recent report on renewables in the National Electricity Market (Blakers, 2017) and in a report by local researchers (Rose, 2016). The state has potential sites for pumped hydro storage between cliff-top ponds and the ocean, and the now under-utilised dams that previously contributed most of Perth's water supply, could also play a part. It is estimated that approximately 40% of the capacity of just five of the water supply dams adjacent to the metropolitan area could provide the 32,000 MWh required by 2050. This would save a considerable portion of the capital costs of completely new systems.

Summary

Two complementary system dynamics models were used to analyse the performance of renewable energy sources on the SWIS:

- a monthly model that runs to 2050 which projects demand, and the take-up of private solar and energy storage at household and business premises; and
- an hourly model that operates across a given year to ascertain the performance of the projected combinations of private solar and storage with large scale renewable energy sources and energy storage.

The analysis suggests that in 2020 private systems will likely produce only about 12% of energy demand. However by 2050 some 60% of households and 50% of commercial premises could have solar PV systems, with around 80-90% of these premises having battery storage systems. This amounts to some 21,000 MW of nameplate solar capacity and 32,000 MWh of storage. This private generation is sufficient to produce around 85- 90% of projected electricity demands from the SWIS area. This scenario would completely change the historical arrangements under which electricity is predominantly provided though a centralised network. The future network will be mainly associated with storing privately generated solar energy and providing complementary energy sources to match supply with demand.

Given the strong momentum for private solar, it is questionable whether in the interim period it is necessary or indeed economically viable to introduce large scale renewable energy to the network with the objective of eliminating greenhouse gas emissions from electricity. It may be more appropriate to allow private generation to largely meet this objective while planning for a completely renewable system by 2050.

By 2050 it is projected that only around 2,250 MW of large scale renewable energy will be needed to complement private solar PV. This energy could be wind energy, or a combination of wind and wave energy. Large scale solar energy is obviously also viable as a generation source, although will require significantly larger energy storages to balance supply and demand.

In order to avoid very large storages it will be necessary to retain fast response thermal generation, most likely using state of the art open cycle gas turbines fuelled by renewable sources such as biogas from organic wastes.

The SWIS will likely require around 32,000 MWh to complement the private storage by 2050, with pumped hydro utilising Perth’s water supply dams, a potential source.

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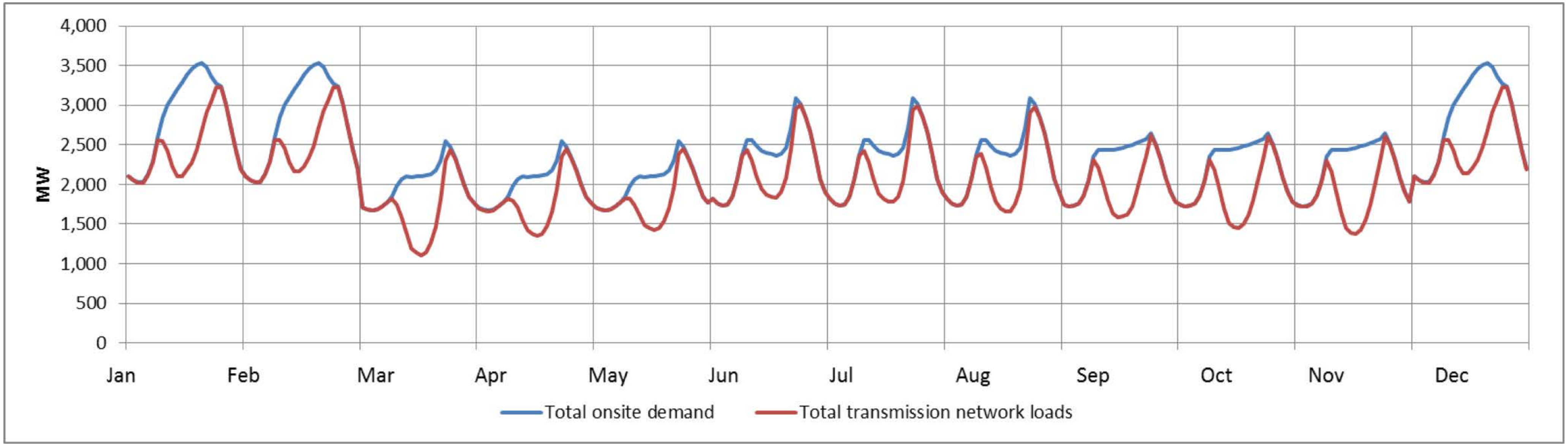

Figure 11a) 2020 Onsite demand, network loads (typical day)

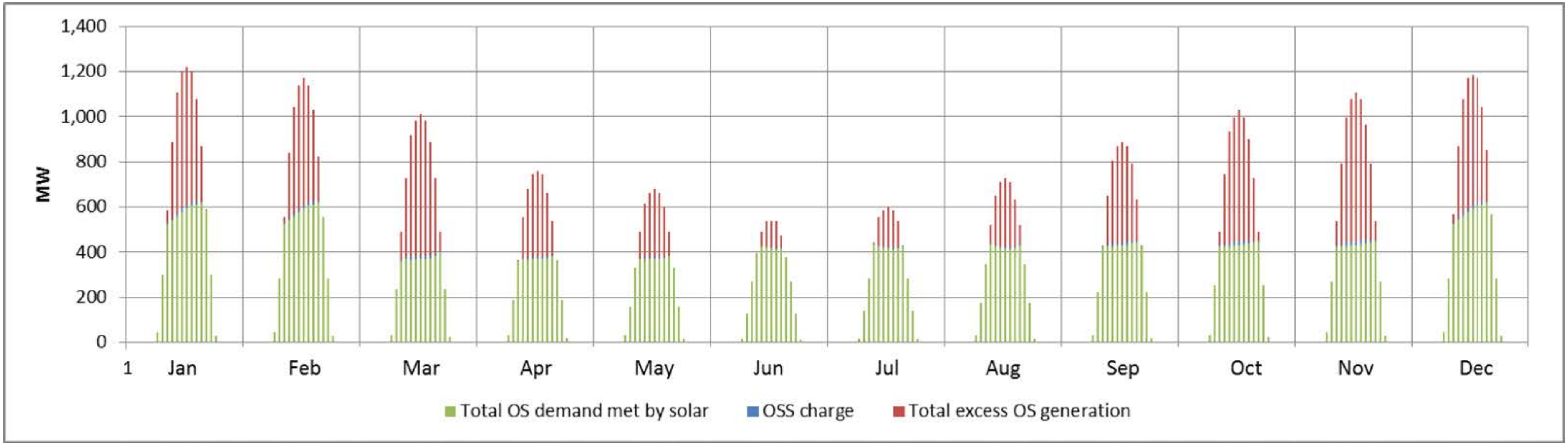

Figure 11b) 2020 Performance of onsite solar PV systems (typical day)

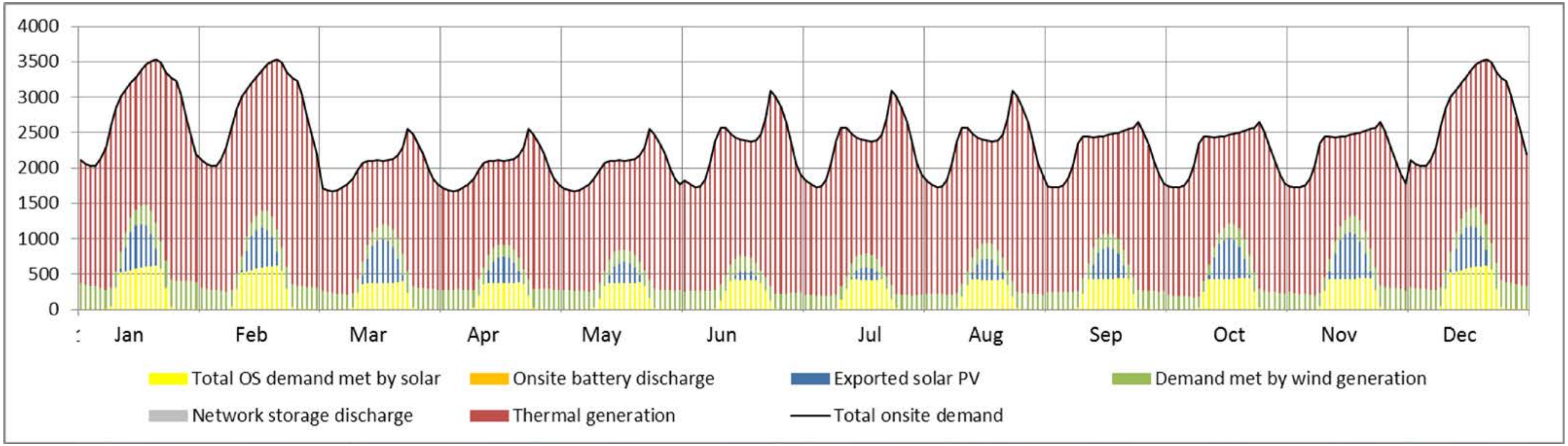

Figure 11c) 2020 System supply (typical day)

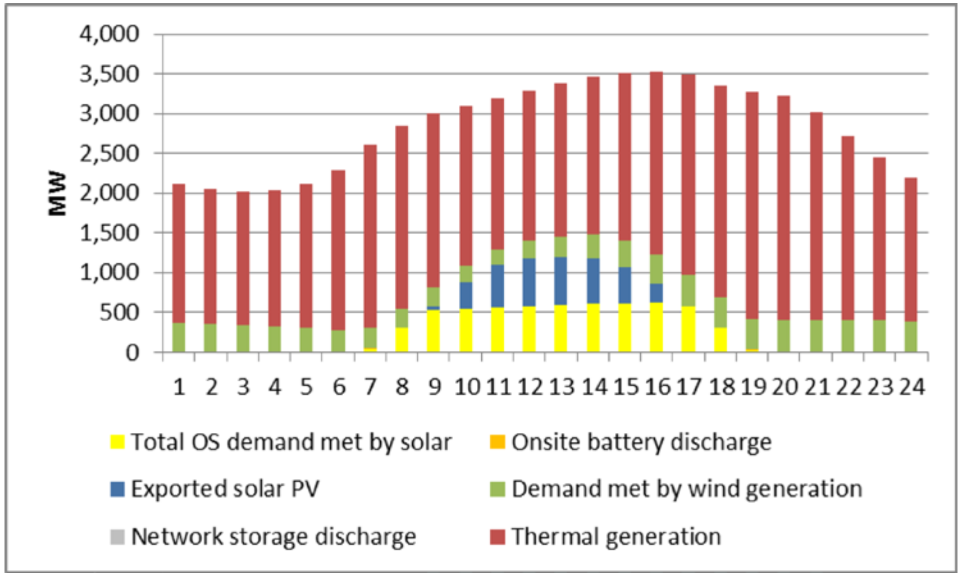

Figure 11d) 2020 System supply (typical January day)

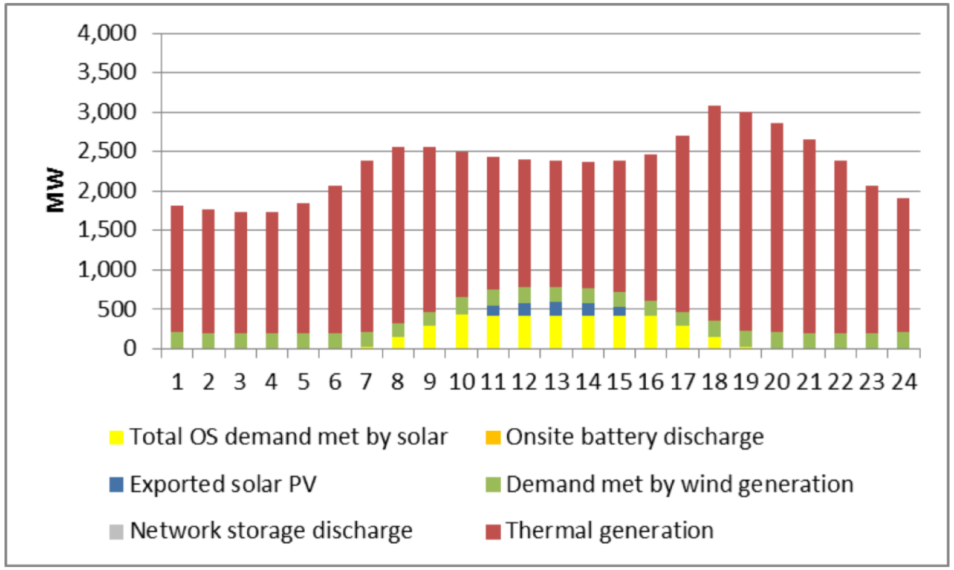

Figure 11e) 2020 System supply (typical July day)

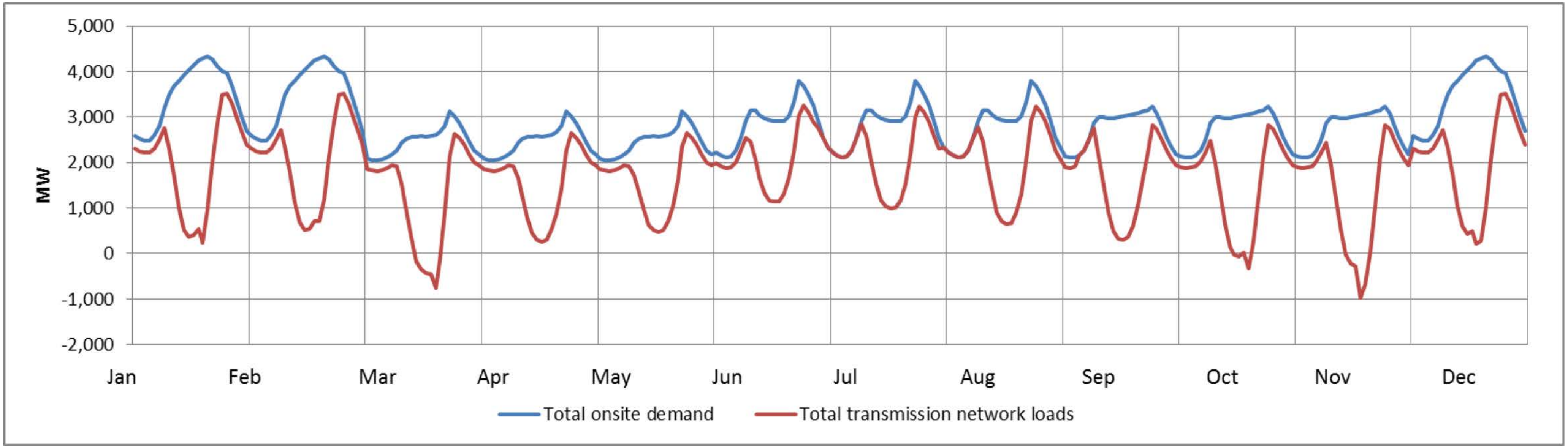

Figure 12a) 2030 Onsite demand, network loads (typical day)

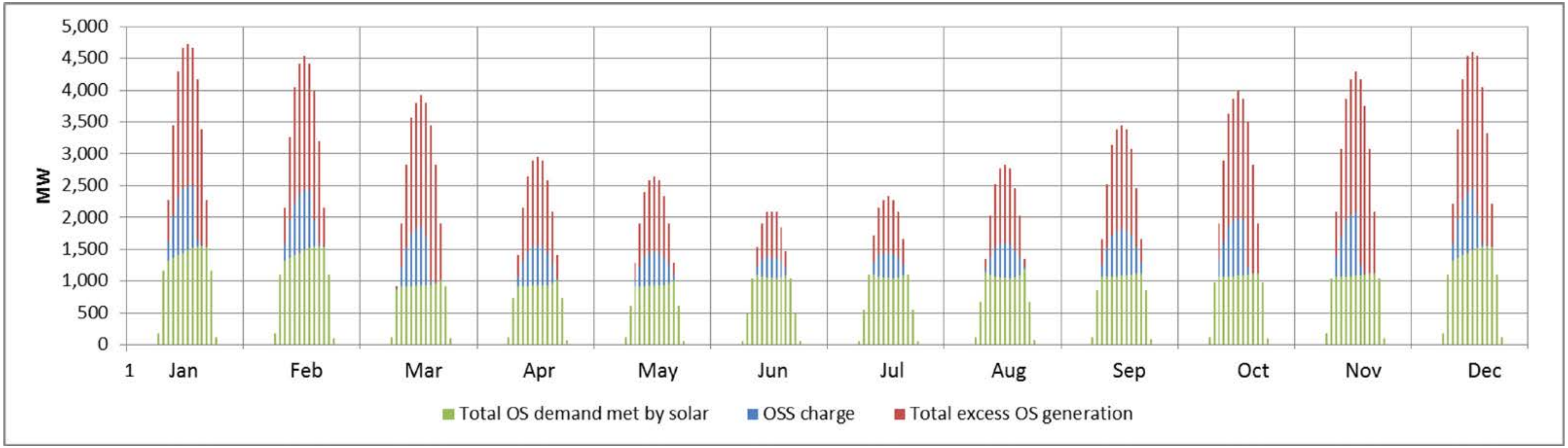

Figure 12b) 2030 Performance of onsite solar PV systems (typical day)

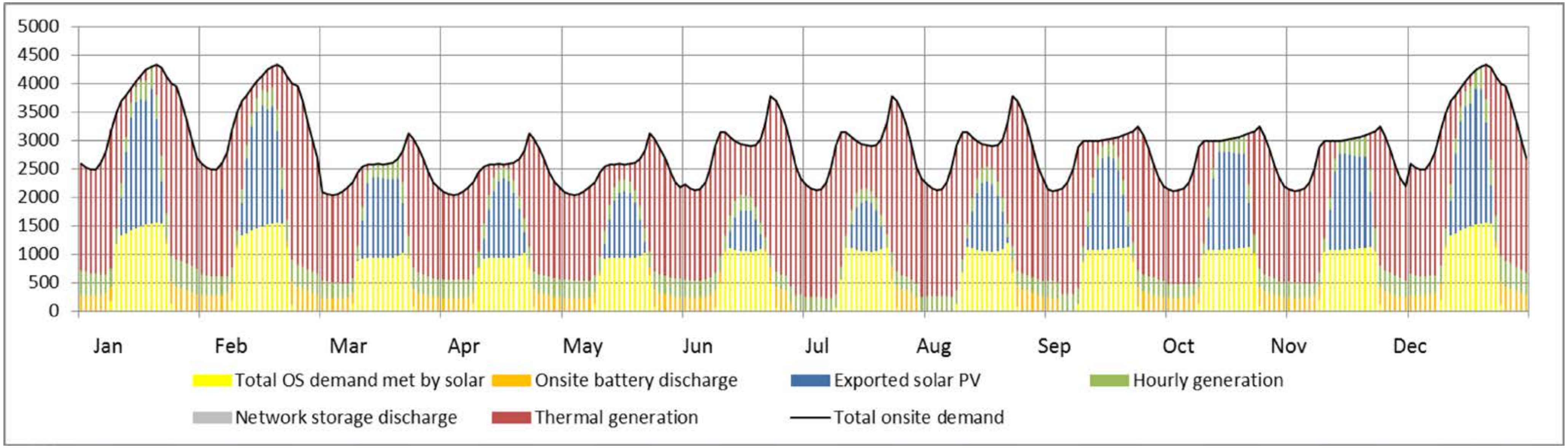

Figure 12c) 2030 System supply (typical day)

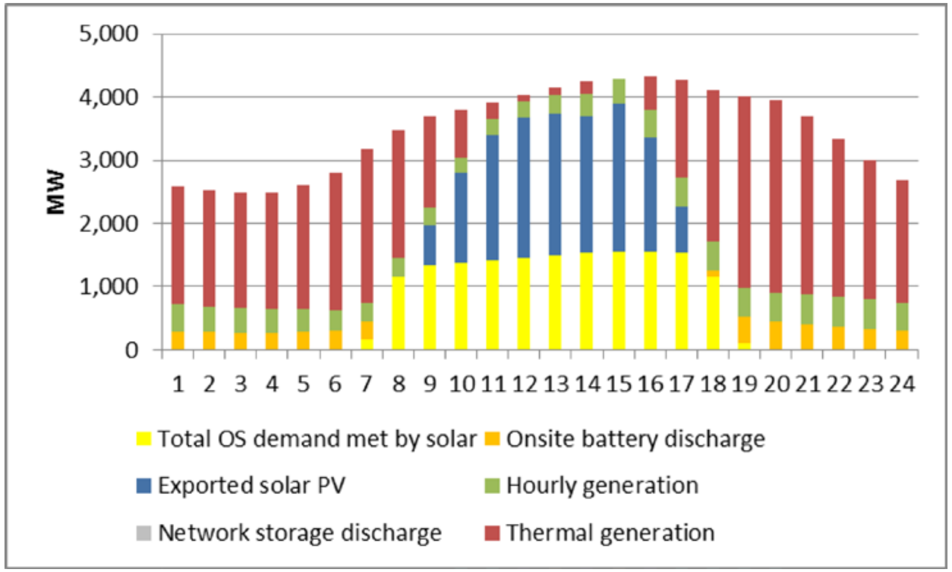

Figure 12d) 2030 System supply (typical January day)

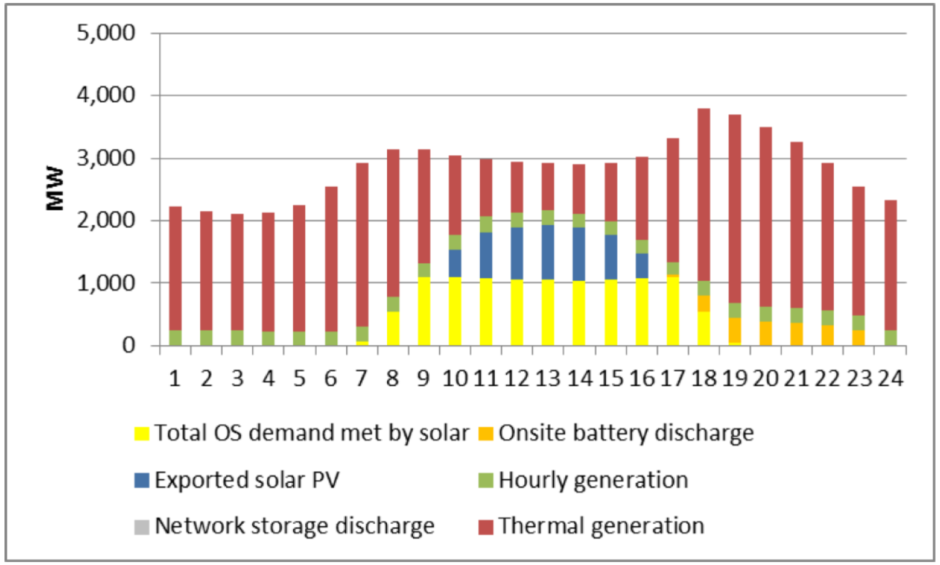

Figure 12e) 2030 System supply (typical July day)

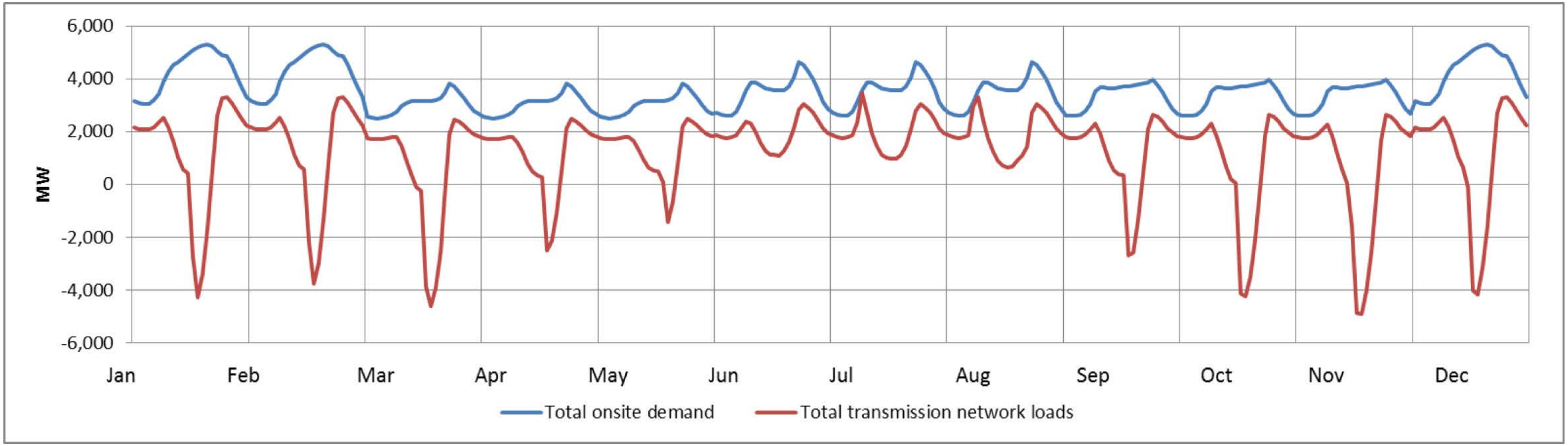

Figure 13a) 2040 Onsite demand, network loads (typical day)

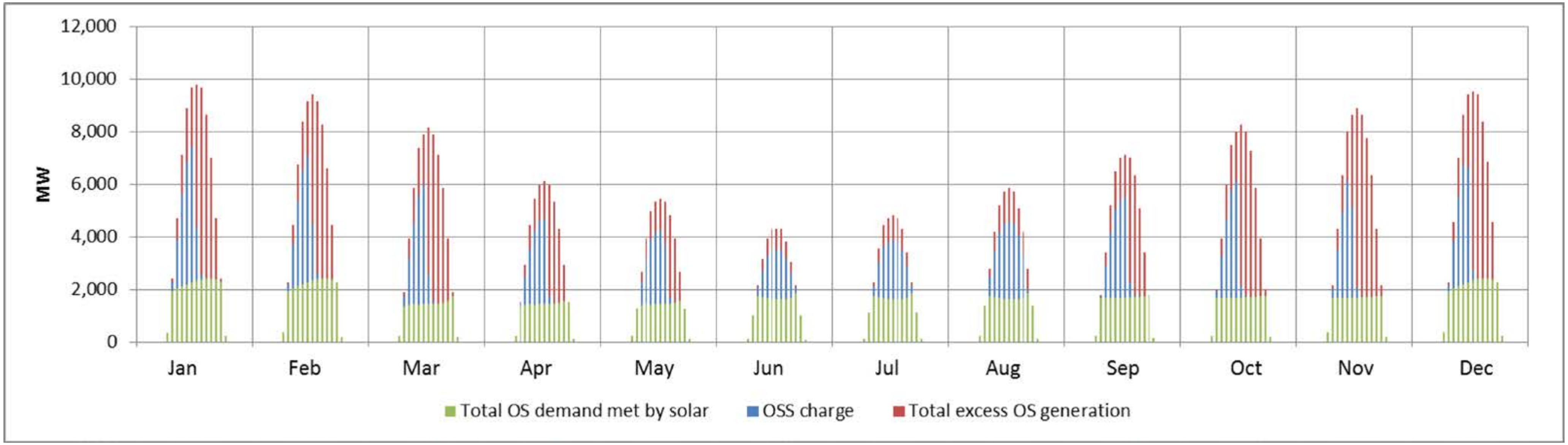

Figure 13b) 2040 Performance of onsite solar PV systems (typical day)

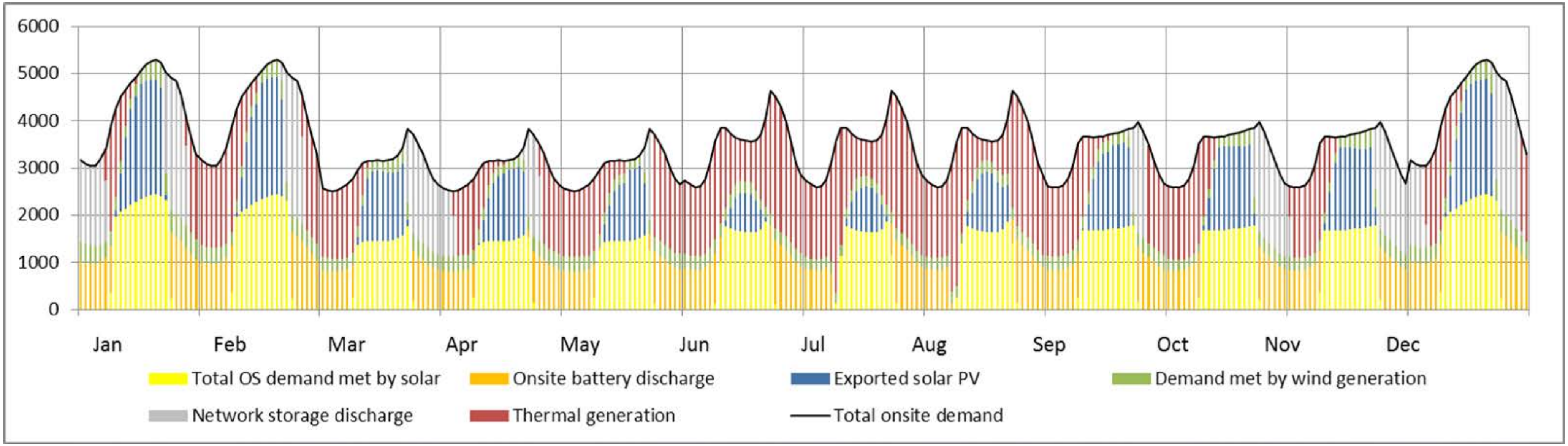

Figure 13c) 2040 System supply (typical day)

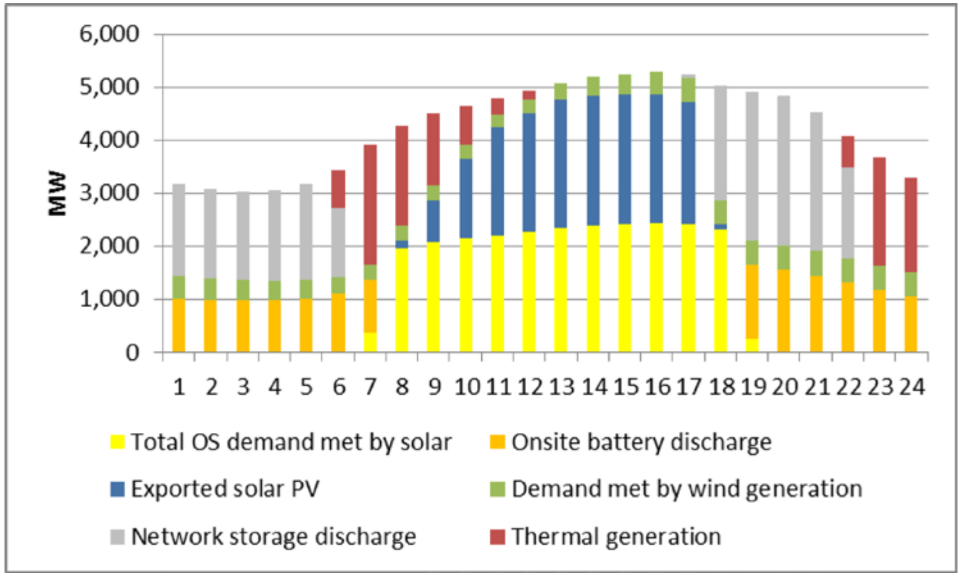

Figure 13d) 2040 System supply (typical January day)

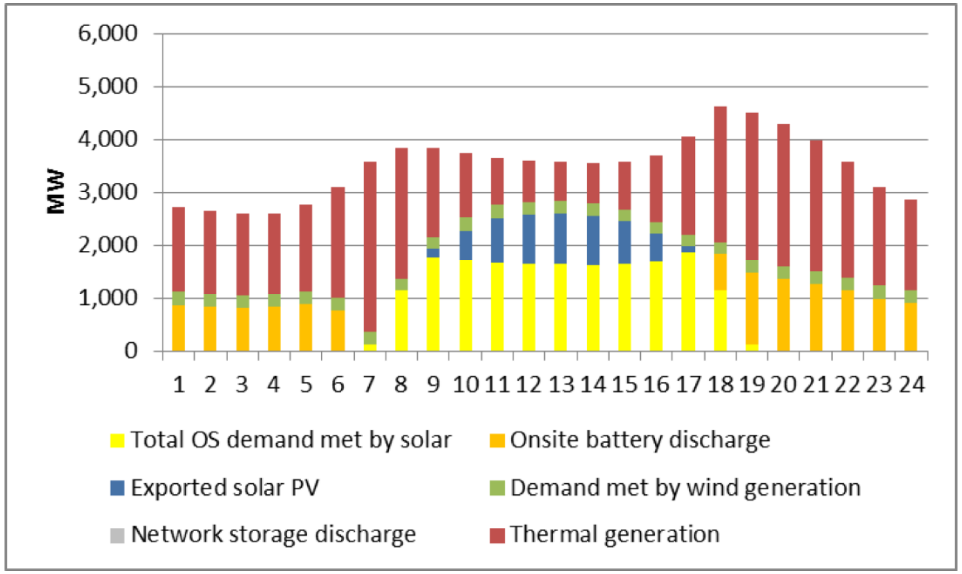

Figure 13e) 2040 System supply (typical July day)

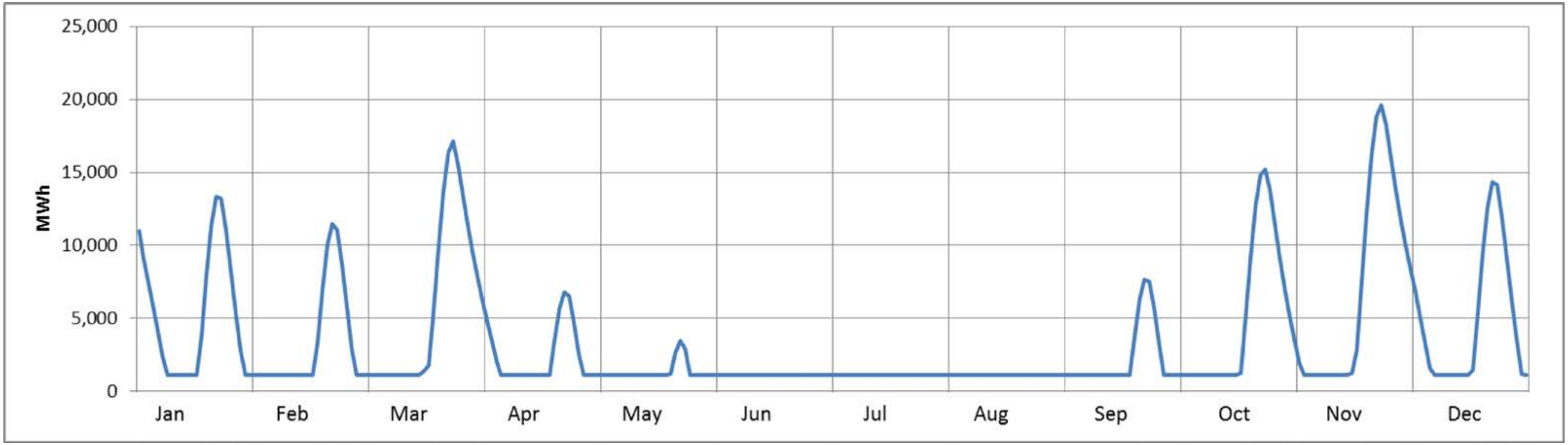

Figure 13f) 2040 Network storage (typical day)

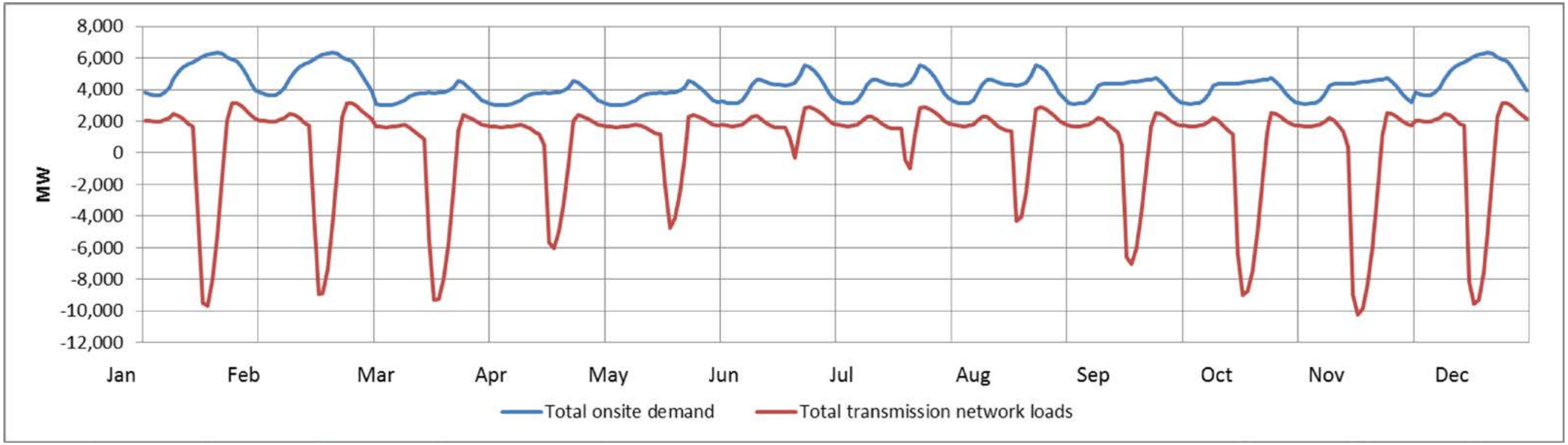

Figure 14a) 2050 Onsite demand, network loads (typical day)

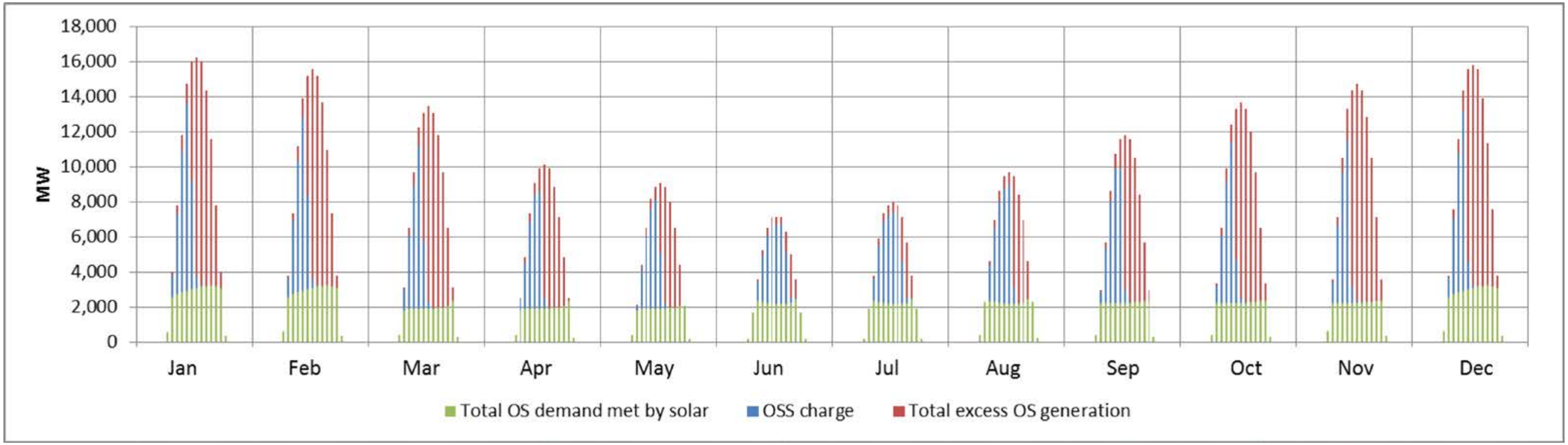

Figure 14b) 2050 Performance of onsite solar PV systems (typical day)

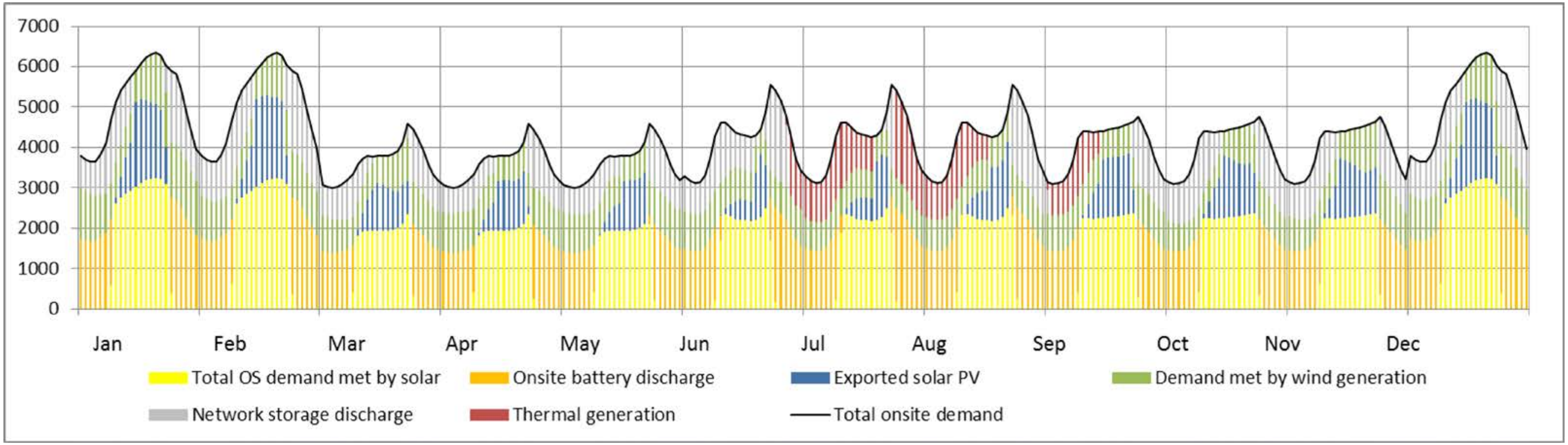

Figure 14c) 2050 System supply (typical day)

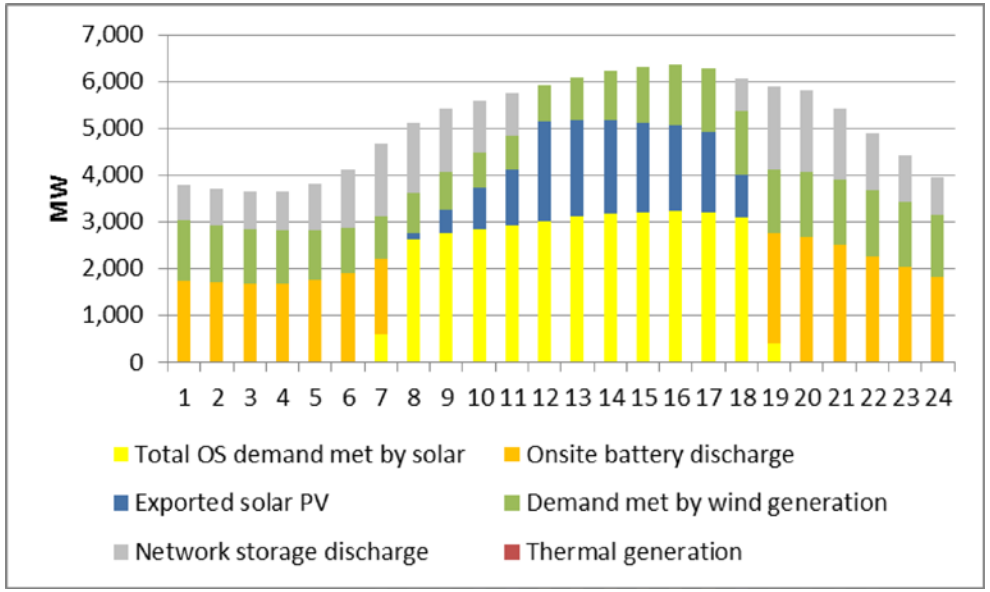

Figure 14d) 2050 System supply (typical January day)

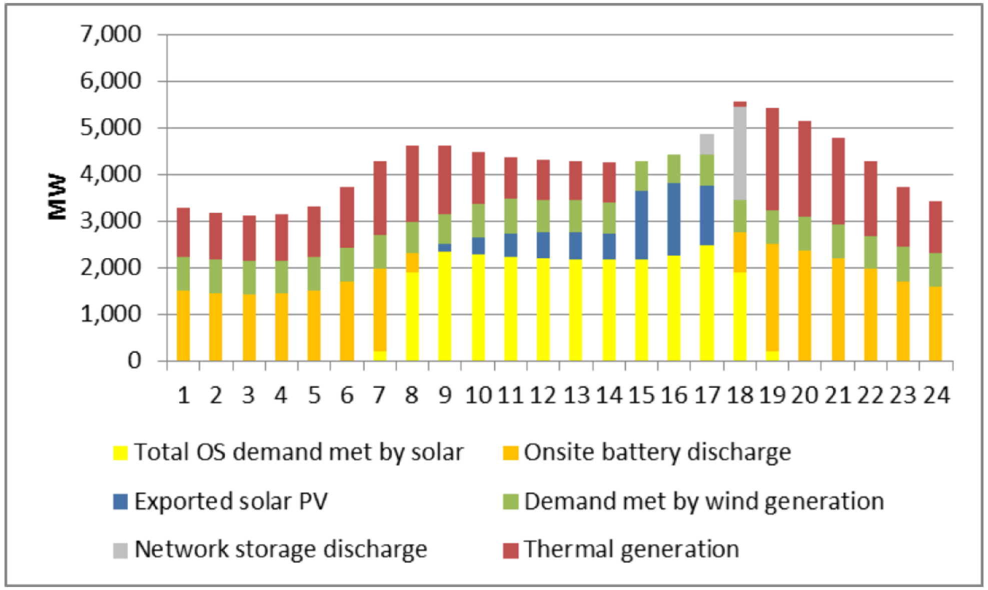

Figure 14e) 2050 System supply (typical July day)

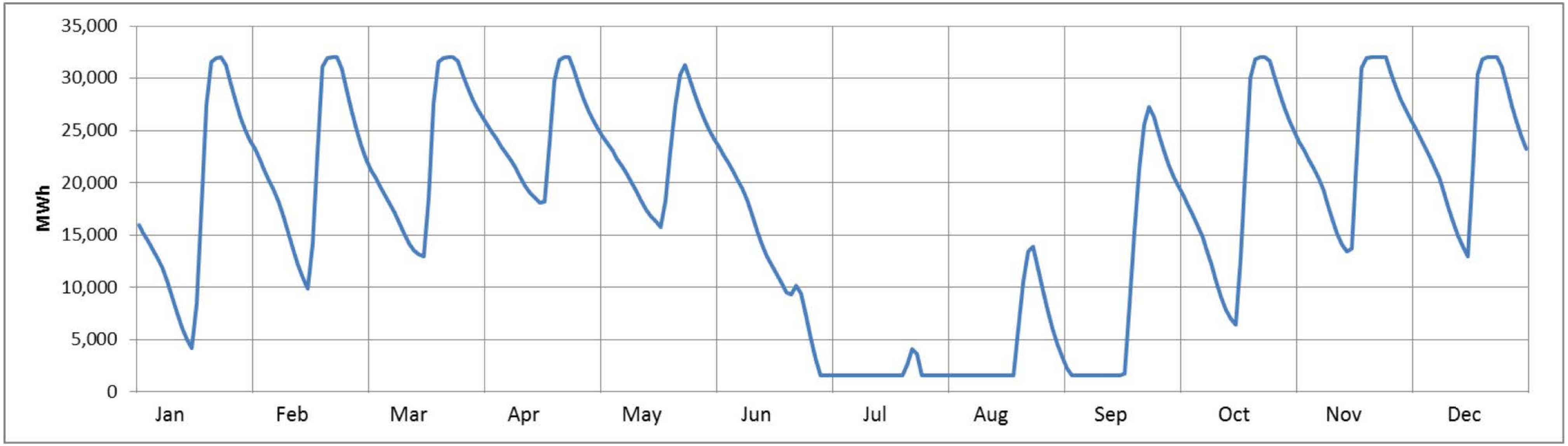

Figure 14f) 2050 Network storage (typical day)

Attachment A

Stock and flow structure of hourly model (network portion only)