Enabling residential rooftop solar

CP BUS 6.02 - Solar enablement - Jan2020 - Public

Regulatory proposal 2021–2026

CitiPower

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Contents

1 Overview

Context for enabling more solar

Our customers have more choice in meeting their energy needs than ever before. They can choose between fuel sources, retail plans, whether to purchase green electricity, or whether they generate electricity themselves—particularly through rooftop solar.

Our engagement activities over the past two years have demonstrated that our customers want to connect and export their excess solar into the network. They are choosing exports to lower their bills, have greater energy independence and build a sustainable future.

In the future, exports will also enable customers to participate in new markets such as wholesale price arbitrage and network support that will improve the efficiency of the electricity market and lower its cost. Without access to these markets, the usefulness of solar and value of the substantial solar investments made by customers and the Victorian Government under its Solar Homes Program subsidy (**Solar Homes**) will not be fully realised.

We are supportive of the energy transition and customers' right to choose how they use or generate electricity—we believe part of our social obligation is accommodating broad trends in the way customers use electricity. This is particularly important given customers do not have a choice between distributors.

In this context, we recognise it is increasingly untenable for us to constrain solar and the choices it enables.

Solar constraints

Solar exports cause network voltages to rise and when they rise sufficiently high, customers' solar inverters trip off and stop generating for both in-home consumption and for exports. If we do not prepare the network for the solar being connected, in 2025 the annual amount of constrained solar generation across our three networks will be equivalent to the annual output of 2.4 Northern Victoria Karadoc solar farms.[1]

Figure 1 Karadoc solar farm

Source: CitiPower

[1] Based the rated capacity of Karadoc and AEMO's published capacity factor for Northern Victoria solar farms.

This doesn't meet our customers' expectations or those of the Victorian Government whose Solar Homes program is a key pillar of meeting the legislated target for 40% renewable energy by 2025.[2]

Approach to enabling solar

We have worked closely with our customer and stakeholders for two years to shape our approach to enable more solar. They told us:

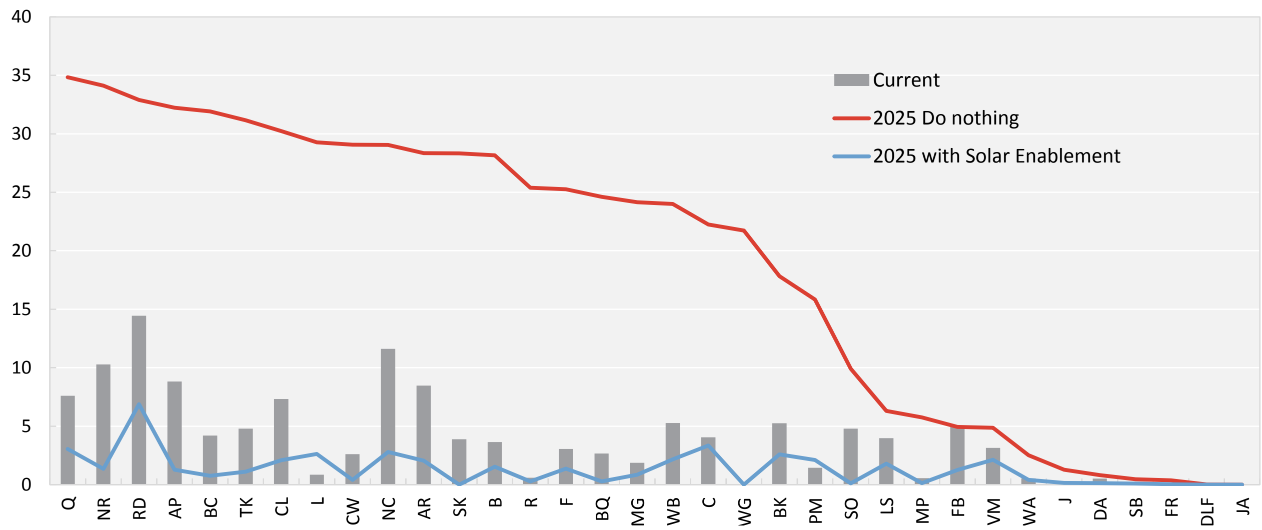
- a 'first in first served' approach to connecting solar isn't fair; all customers should be able to export some solar
- some solar constraints can be tolerated but network investment is needed to ensure they aren't excessive
- overall affordability is important.

The outcome from this engagement is that we will:

- enable 5kVA solar systems available for export for the large majority of customers
- remove solar constraints where it is efficient to do so; where the benefits to customers outweigh the costs
- for those customers where it is uneconomic to remove constraints (typically customers connected to smaller transformers), we may need to limit export connections once local penetration becomes too high. However, we have developed a parallel program to ensure these customers can still get the most out of their solar.

By undertaking planned and targeted investment, we'll unlock over 95% of the solar that would otherwise be constrained while maintaining affordability. Figure 2 shows the percentage of time solar is constrained due to high voltages now, in 2025 if we do nothing and in 2025 after this Solar Enablement program for each zone substation on our network.[3]

Figure 2 Solar constraints by zone substation (percentage of daylight hours)



Source: CitiPower

2 *Renewable Energy (Jobs and Investment) Act 2017*

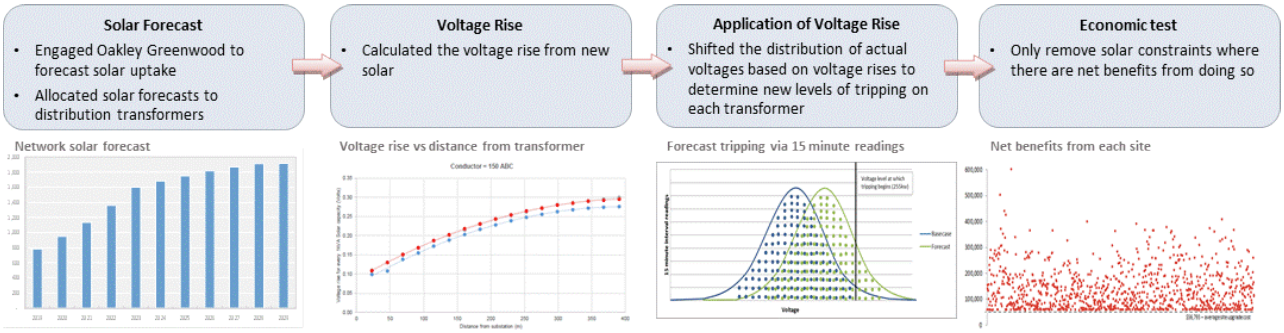
3 Only shows data for the transformers considered as part of this Solar Enablement business case; excludes transformers 50kVA and below.

If we undertake no action to accommodate solar, by 2025 the average customer on 59% of our zone substations will experience constraints more that 20% of the time.

Our modelling

We have maximised the benefits from our investment by using over 38 billion actual data points from our Advanced Metering Infrastructure (**AMI**). The information has enabled us to pinpoint the least cost way to address a constraint, including by applying smart settings to customers' solar inverters, implementing a Dynamic Voltage Management System to lower network voltages at high solar export times, 'tapping' down distribution transformer (**transformer**) voltages and undertaking efficient network investment. From this we have ensured the maximum benefits from our investment. Figure 3 summarises our modelling approach.

Figure 3 Overview of modelling approach



Source: CitiPower

Enabling efficient solar

The net benefit to our customers of this program is over $32 million. The benefits we have calculated are the reduction in wholesale generation fuel costs and carbon reduction benefits from solar; benefits that all our customers (even those without solar) receive.

Targeted investment is required to unlock these benefits and ensure we can accommodate the new trend in solar. Table 1 presents a summary of this expenditure breakdown.

Table 1 Investment summary

	Capital investment	Operational investment
Dynamic Voltage Management System	1,051	-
Tapping	-	691
Network investment	30,193	-
Compliance and monitoring	-	460
Total	**31,244**	**1,151**

Source: CitiPower

Structure

The remainder of this business case is set out as follows:

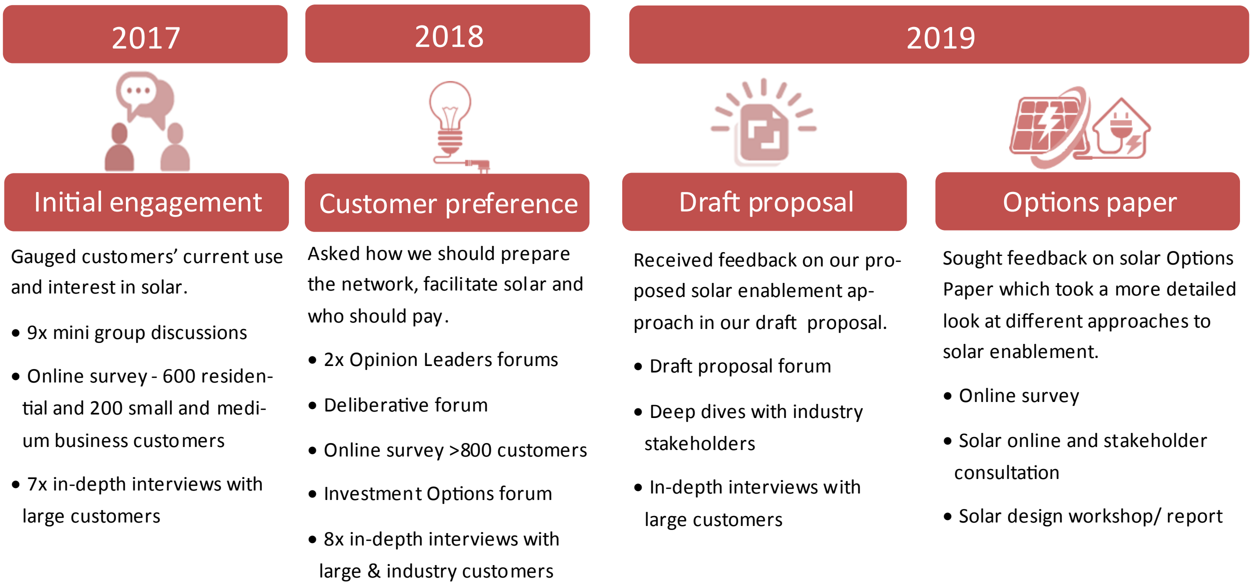
- **Background**—provides the solar forecast for our network and considers the network capacity to accommodate it
- **Identified need**—discusses the reasons to accommodate more solar
- **Options analysis**—outlines options for accommodating more solar and considers their merits
- **Solar Enablement program**—details this Solar Enablement program and the way we are ensuring our investment is targeted and efficient
- **Results**—presents the results of our analysis and the investment forecast
- **Summary of attachments**—lists the documents supporting this business case.

2 Background

2.1 Our engagement journey

Since 2017, we have heard from thousands of our customers about their solar expectations, which has been critical in shaping our decision and approach to enable more solar. Figure 4 summarises the engagement process that we have undertaken.

Figure 4 Our engagement journey



Source: CitiPower

A key stage of this process was our solar deep dive, where stakeholders told us the approaches to enabling solar we were considering at the time were too limited in scope. As a result, we developed and consulted on our 'Enabling rooftop solar exports – options paper' (**Options Paper**).[4] Feedback on this process has played a pivotal role in shaping our approach.

Throughout this business case we discuss the views that our customers have expressed to us. We haven't always implemented the majority preference, however these preferences have all been considered. Where we have taken a different approach to our customers' views, we discuss the reasons for it in this business case.

2.2 The number of solar installations is increasing

In August 2018, the Victorian Government announced a 50% rebate for up to 650,000 homes and 50,000 rental properties to install solar panels over 10 years.[5] The Victorian Government expects this program to save Victorians $890 on their electricity bills each year and generate 12.5% of Victoria's target for 40% renewable energy by 2025.[6]

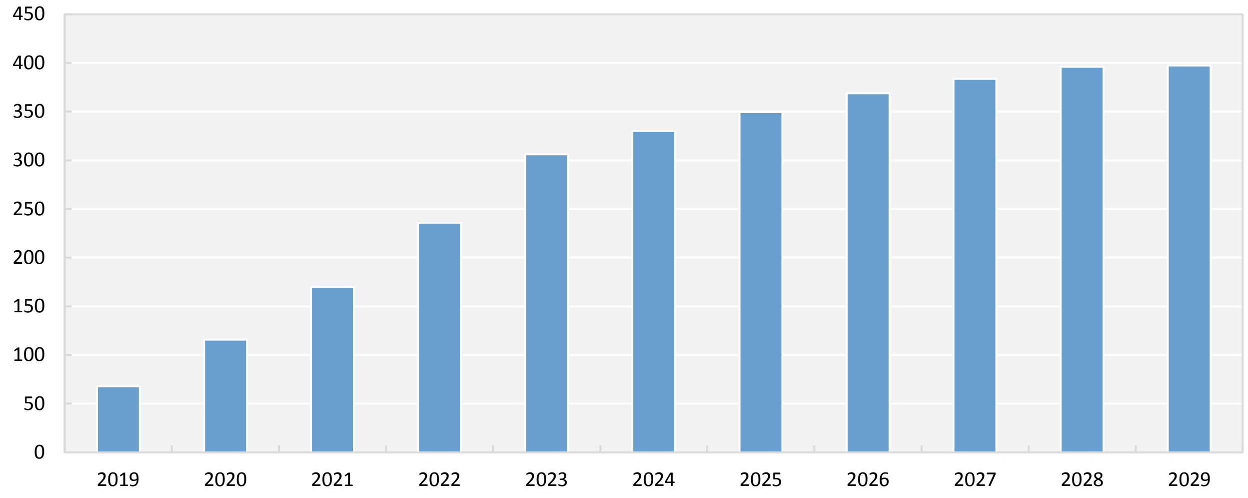
4 CP ATT220: Available at Talking Electricity website <https://talkingelectricity.com.au/wp/wp-content/uploads/2019/05/Solar-options-paper_May-2019.pdf>

5 Based on a 4kW sized system.

6 CP ATT173: Victorian Government, Cutting Power Bills With Solar Panels For 650,000 Homes <https://www.premier.vic.gov.au/cutting-power-bills-with-solar-panels-for-650000-homes/>

We engaged independent consultant Oakley Greenwood to forecast the solar uptake on our network, including the impact of the Solar Homes program. The Oakley Greenwood solar forecast report is attached.[7] The forecast of residential solar customers is also discussed in appendix B and shown in figure 5.

Figure 5 Cumulative residential solar uptake (MW)



Source: Oakley Greenwood forecast for CitiPower

The capacity of installed solar on our network is forecast increase rapidly with solar penetration growing from 4% today to 24% in 2025.[8] This is consistent with impact of the Solar Homes program already being seen with our monthly solar connections having increased by 74% from the previous level. The forecast represents 11% of the solar that will connect under the Solar Homes program by 2029.[9]

2.3 Network voltages are rising due to increasing solar penetration

To enable exports, customers' solar inverters operate at a higher voltage than the network to 'push' the solar electricity back into the network. This causes the localised network voltage to rise.

When voltages reach either 255 volts (**V**) for 10 minutes or 260V for 2 seconds, customers' solar inverters trip off as a safety measure to protect the network from damage.[10] Under new inverter settings we will be requiring solar installers to apply to help address this, solar output will progressively reduce between 253V to 259V and will trip when voltages are sustained at 258V for 10 minutes. When solar inverters trip they are incapable of both exporting and producing solar for in-home use.

2.3.1 Voltages on our network

We are in a unique position to understand the voltage impact of solar given the investment made into AMI. Using AMI data analysis, figure 6 shows the maximum voltages of a transformer that experienced a 40% increase in solar penetration from January 2017 to March 2019.

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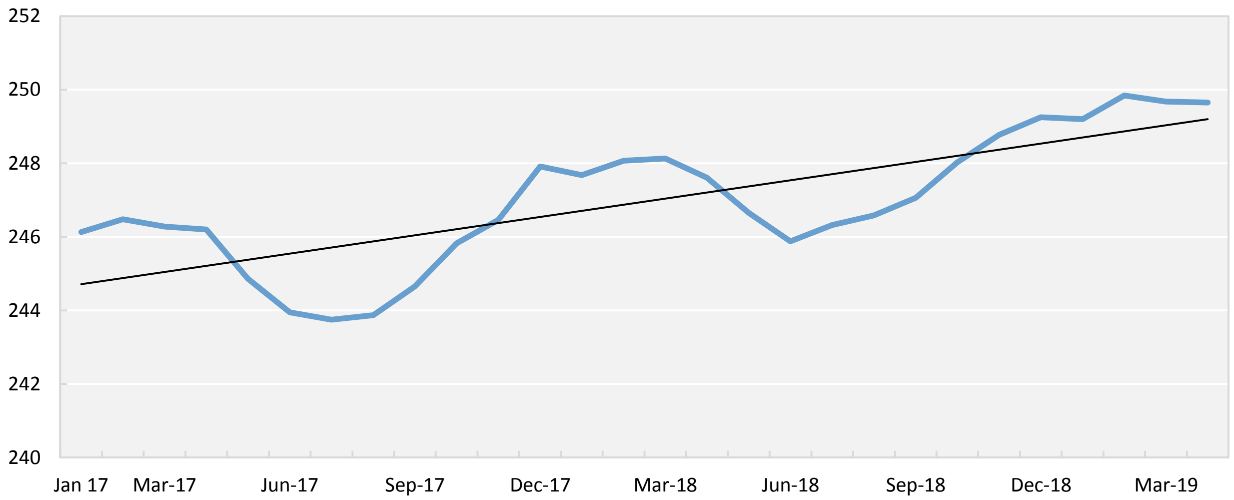
7 CP ATT004: OGW, *Profiling uptake of solar*, March 2019.

8 Measured as a percentage of total customer numbers.

9 Based on 650,000 additional solar connections by 2029.

10 Australian Standard (AS) 4777.

Figure 6 Maximum voltage on transformer as solar penetration increases

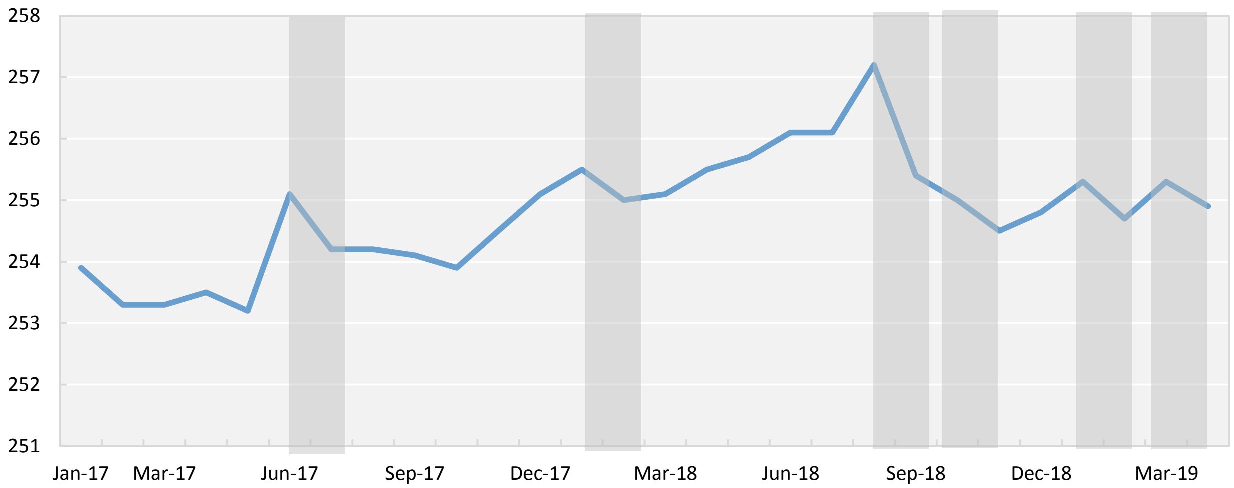


Source: Powercor, United Energy and CitiPower

This figure demonstrates that voltages rise as solar penetration increases. It also shows the seasonal impact of solar exports on voltages—in the months with higher solar irradiance and exports, voltages increase.

Figure 7 shows the maximum monthly voltage from the 25 transformers with the highest solar growth from January 2017. The grey bars indicate when we have tapped down voltages on some of these transformers.

Figure 7 Maximum voltage per month on transformers as solar penetration increases



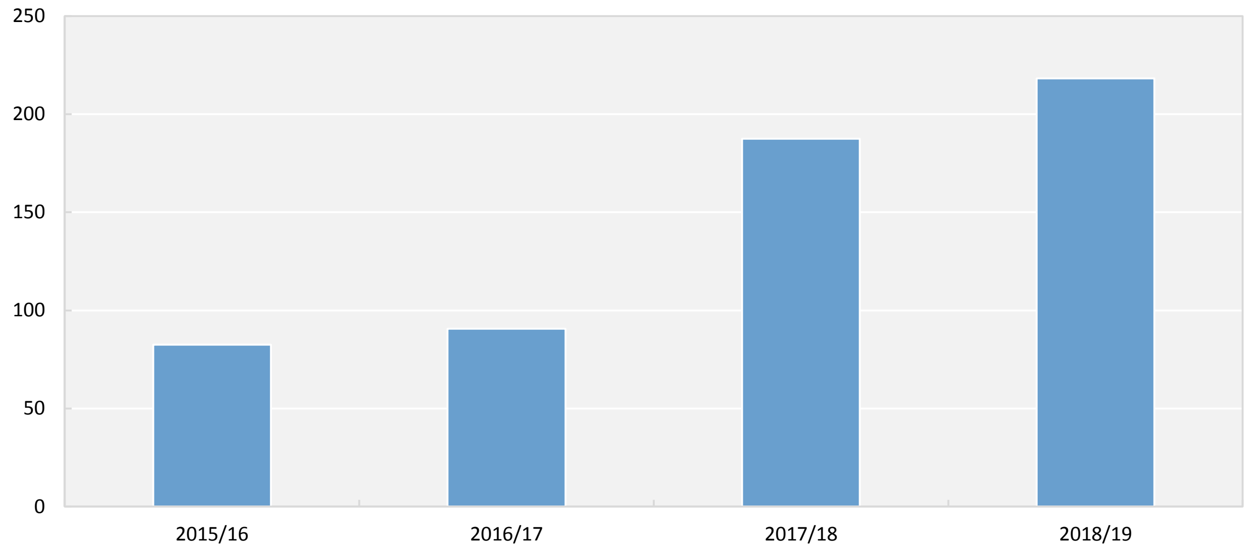
Source: Powercor, United Energy and CitiPower

This also illustrates that maximum voltages rise as solar penetration increases and the overall high voltages that are experienced on high solar penetration transformers.

2.3.2 Customers' solar experience

The voltage rises we are already experiencing due to solar connections are also having a noticeable impact for customers. Figure 8 outlines the number of supply quality enquires we have received.

Figure 8 Number of solar voltage enquiries



Source: CitiPower

This indicates that as solar penetration increases, increasingly customers are becoming dissatisfied with the solar constraints they face. Solar and non-solar customers are also seeing the impact of voltage variations such as flickering lights and changes to the performance of equipment.

3 Identified need

We have identified the following need for changing our approach to accommodating solar:

1. ensure we are maximising net benefits to customers from solar
2. meet our customers' expectations to export excess solar and facilitate the Victorian Government's Solar Homes policy
3. contribute to our voltage obligations under the Electricity Distribution Code (**Code**).

These are discussed in more detail below.

3.1 Customer benefits from solar generation

The primary identified need of this business case is to maximise the net benefits to customers from solar. This is consistent with the National Electricity Objective (**NEO**), which is to promote efficient investment for the long term interest of consumers.

To value the benefits from solar, we looked to the Australian Energy Regulator's (**AER**) RIT-D which outlines 'changes in fuel consumption arising through different patterns of generation dispatch' as a market benefit class.[11] Solar generation displaces generation from other (limited) fuel sources such as coal or gas, which generates an economic benefit. The fuel cost saving can also place downward pressure on wholesale electricity prices.

We also included the carbon reduction benefit from solar because tackling climate change and providing a cleaner future are key aims of the Victorian Government's Solar Homes program.[12] If we were to exclude the carbon reduction benefit, we would be undervaluing the Victorian Government's policy decision by enabling less solar than is economically justified by the program's intent.

Importantly, in Australia carbon is no longer an externality but rather is a priced commodity. The Australian Government's Emission Reduction Fund is the centrepiece of the Australian Government's carbon policy. As outlined in its White Paper:[13]

> *The Government is committed to practical actions that will achieve real, measurable results for the environment. The Emissions Reduction Fund is a central component of the Government's [plan]*

Enacted through the *Carbon Credits (Carbon Farming Initiative) Act 2011* and associated regulations, the Emissions Reduction Fund places a price on carbon as measured by the Australian Carbon Credit Units.[14] The prevailing carbon price under Emission Reduction Fund's June 2019 auction was $14.17 per tonne of carbon.[15]

Our customers, particularly local councils that have set local carbon reduction targets for themselves, were highly supportive of including the carbon price as a benefit from this program.[16]

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11 CP ATT214: AER, Application guidelines Regulatory investment test for distribution December 2018. The AER will we will accept this classes of market benefits as relevant if the RIT–D proponent requests the AER's approval to include it in a RIT-D

12 Solar Homes Victoria <https://www.solar.vic.gov.au/>

13 CP ATT215: Australian Government, Emissions Reduction Fund White Paper, April 2014, Minister's foreword.

14 CP ATT218 We note Emission Reduction Fund was further topped up by the Australian Government by an additional $2 billion in 2019. Department of the Environment and Energy <https://www.environment.gov.au/climate-change/government/emissions-reduction-fund/about>

15 CP ATT219: Clean Energy Regulator <http://www.cleanenergyregulator.gov.au/ERF/Auctions-results/july-2019>

16 CP ATT217: See for example the Geelong Council Zero Carbon Emissions Strategy where over 80% of community respondents agree that minimising climate change impacts in the Geelong region is very important. <https://www.geelongaustralia.com.au/zerocarbon/article/item/8d4907fc1776c46.aspx>

Changes in fuel consumption and carbon reductions are the key benefits that have been quantified in this business case, which are received by all our customers, not just those with solar.

There are also important longer term benefits from enabling solar generation that we have not quantified. The Australian Energy Market Commission (**AEMC**) has highlighted that exports will allow customers to participate in a raft of new markets in the future, including:[17]

- engaging in local energy (peer-to-peer) trading—buying and selling electricity from other customers rather than from central generators
- retail and wholesale electricity price arbitrage activities—selling exported electricity to third parties (such as retailers) to avoid that party having to purchase wholesale electricity
- wholesale market support—selling electricity at times of wholesale generation shortfalls
- transmission congestion management and distribution network investment deferral—selling electricity at times of peak load on the networks to avoid the need for capacity driven network investments.

These new markets improve the efficiency of the electricity market operations and reduce overall costs. They also create value for solar customers who will be paid for participating in them. Without exports, these markets will not properly develop and the value of the substantial solar investments made by customers and the Victorian Government will be stifled. We have not quantified these benefits (meaning we are understating the benefits from this program), but they form a key driver for considering ways to enable more solar exports.

3.2 Customers are choosing to export

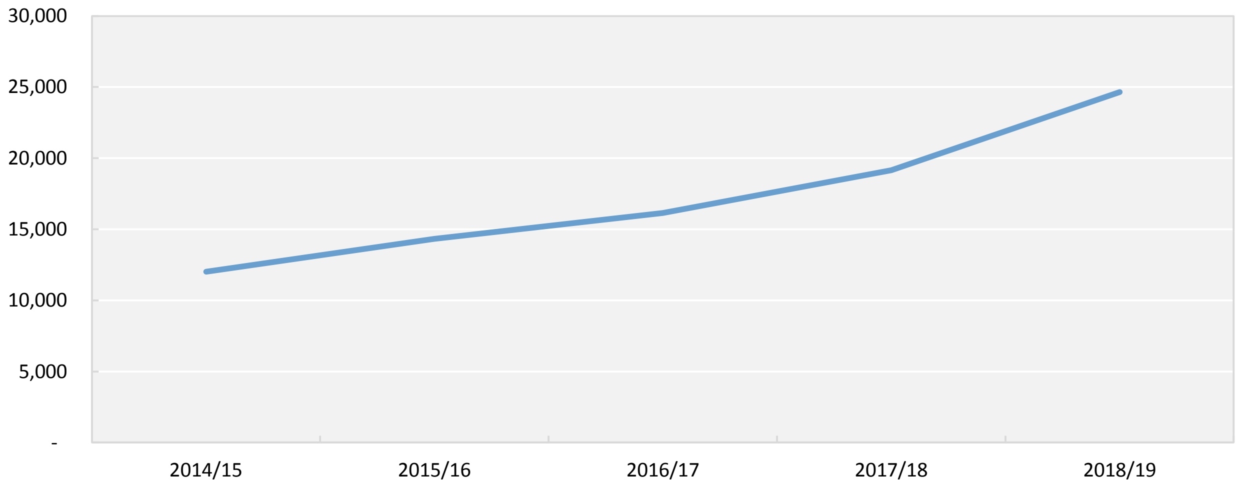
Our engagement over the past two years has demonstrated that our customers want to export solar electricity to:

- lower bills
- have greater energy independence
- build a sustainable future.

Customers' preferences to export solar are also revealed by looking at the increasing trend in total exports on our network, which are shown in the figure below.

[17] CP ATT216: AEMC, Distribution Market Model, August 2017.

Figure 9 Yearly exports (MWh)



Source: CitiPower

Exports have more than doubled over the past four years, with more than 40% of this increase occurring over 2018/19.

Customers' expectations to connect export capable solar without experiencing excessive tripping has also been demonstrated by the enquiry data that was outlined in section 2.3.

As the only provider of distribution services to customers in our area, we must be a facilitator and not a barrier to customer trends, particularly when those trends provide benefits to all customers. We need to accommodate customers' choices in the same way businesses operating in competitive markets must adapt.

As far as practicable, we should also facilitate the Victorian Government's policy decision that more customers should benefit from solar.

We consider these reasons form a part of meeting our social obligation for operating a distribution network. This social obligation, however, also requires we balance these considerations with affordability, a factor which 94% of customers considered important. The way we have balanced customers' identified needs is discussed in the following chapters.

3.3 Voltage compliance

We have obligations under the Electricity Distribution Code (**Code**) to keep voltages at the point of connection within 253V.

Code compliance is not a standalone identified need because it could lead to untenable and uneconomic outcomes. For example, meeting the Code requirements with respect to solar could be achieved by:

- restricting all exports
- allowing all exports and undertaking significant (and uneconomic) network investment.

Both of these options are a simplistic view that does not take customer preferences into account. Therefore we consider any approach to enabling solar should contribute towards, rather than detract from our Code obligations—particularly given these obligations are in place to protect customers from poor supply quality—but not target Code compliance as the primary outcome.

4 Options analysis

This section summarises the options considered, outlines the way customer feedback has shaped the options and presents the recommendation for enabling solar.

4.1 Summary of options analysis

We conducted forums, surveys, a deep dive workshop, and published and consulted on an Options Paper to develop options for enabling solar.

We considered 7 options in our Options Paper, which covered both ways to enable more solar and the ways in which the costs should be recovered (e.g. through tariffs, connection charges). Feedback on this paper and our other engagement activities has been pivotal in shaping our approach to enabling more solar.

The primary options we have considered are detailed in appendix A and are summarised in the table below.[18] In the below table, Options are presented as the broad ways to enable more solar and Approaches draw out the mechanism and extent to which the option can be implemented.

18 These options have been presented differently from the Options Paper but are the same in substance.

Table 2 Summary of options analysis

Option	Approach	Description	Considerations
Option 1—No action to enable solar	'Unmitigated tripping'	Allow all solar to export but not ready the network for it. Solar inverters will be constrained as voltages rise.	• Overall not supported by customers due to significant constraints • Not based on an economic assessment—assumes the current network hosting capacity of solar is the efficient amount
	'First come first served'	When the local solar penetration creates a voltage constraint, require new solar to be set to 'no exports' (our current approach).	• Not supported due to the inequity of new customers not being able to export • Not based on an economic assessment—assumes the current network hosting capacity of solar is the efficient amount
	Dynamic control	A variation on this Option where we control customers' inverters to reduce exports at times of constraints.	• Dynamic control supported over other forms of tripping. Customers considered reasonable constraints could be tolerated, but could not occur too often. • Not based on an economic assessment—assumes the current network hosting capacity of solar is the efficient amount
Option 2—Behavioural change	Tariff reform	Implement tariffs that encourage customers to use more electricity during periods of solar generation to minimise exports and network voltage constraints.	• Was supported by customers as a complementary option in response to the Options Paper. However, during tariff discussions there was no suggestion tariffs should be designed to enable more solar rather than targeting peak load and reducing cross subsidies. • Unlikely to facilitate much solar on our network and does not lead to the efficient amount of solar
	'Quasi export tariffs'	Reduce the Feed-in-Tariff to encourage solar customers to use more solar generation and orient their panels to maximise generation at peak load times rather than total generation.	• Not supported by our customers or in line with their expectations use solar to lower their bills and achieve greater energy independence • Cannot be implemented by distributors
Option 3—Removing constraints	Alleviate constraints when they appear	Connect solar and remove constraints to avoid constraints—a static approach that considers when solar would begin being constrained, but not how often it would occur.	• The most highly supported standalone option • Based on an economic assessment to determine whether there are net benefits from the program overall, however, was not able to determine the amount of solar to unlock to maximise customer benefits
	Removing constraints when efficient	Connect solar and remove constraints when the value of constrained solar exceeds the cost of removing the constraint—a dynamic approach that considers how often and how many solar customers are constrained. Has been designed in response to customer feedback on other options	• Based on an economic assessment of the efficient amount of constrained solar. This approach maximises the net benefits to customers by only removing efficient constraints

Source: CitiPower

Our recommended Option is the second Approach under Option 3 'Removing constraints when efficient'. Throughout this business case this is referred to as our Solar Enablement program. The reasons for our recommended option are discussed in more detail below.

4.2 How customer feedback has shaped our approach

Feedback to our Options Paper was clear that:

- customers do not support Option 1. Rather, 75% of customers thought we should be doing more to prepare the network for solar. 'Unmitigated tripping' was highly undesirable and the 'first in first served approach' was considered 'un-Australian' and received no support.
- Option 2 received no support as a standalone option. Tariff reforms were accepted as a supporting approach to other Options.
- of all the options and approaches considered, Option 3 was most highly considered to 'make sense'.[19] When we asked stakeholders to rank all of the approaches, 60% of customers also selected this as their first preference. When asked which approach best complemented this option, customers chose 'dynamic control'.[20]
- affordability and reliability are still customers' first preferences.

From this it became clear that customers can tolerate reasonable constraints (their support for dynamic control and affordable prices) but the network must be prepared to accommodate more solar and ensure these constraints are not excessive (their support for Option 3).

We used this feedback to refine our approach to enabling solar to meet our customers' expectations—the approach of 'Removing constraints where efficient' under Option 3. This is a hybrid of Option 1—No action to Enable solar and Option 3—Removing constraints. These concepts are tied together by an economic test; we will allow some (reasonable) level of solar constraint and remove it when the cost of continuing to allow the constraint outweighs the cost of removing it. We will also develop dynamic control capabilities to manage constraints as discussed in section 4.5.

4.3 Options comparison

The approach of 'Removing constraints when efficient' (under Option 3) is the only option that is capable of maximising the net benefits of solar. In contrast to this approach:

- Option 1 performs no economic analysis as to the right level of solar but rather, assume that the network's current hosting capacity is efficient
- Option 2, while supported by customers as an option that could complement another option, comes with uncertainty as to whether it can be implemented and the quantum of its effect. It too performs no economic analysis to determine the efficient constraint level but rather leaves it up to customers' response to determine the outcome.
- the first approach in Option 3 removes constraints as they appear rather than considering the efficient timing and level of constraint. It is also based on a 'first in first served' approach; that is, where it is

19 This was presented as option 7 in the Options Paper.

20 This was presented as option 6 in the Options Paper.

uneconomic to remove constraints we would limit exports from subsequent customers, which our customers rejected.

Given 'Removing constraints when efficient' approach allows us to both optimise the level of investment and the timing of investment is a fundamental factor in its favour compared to other options.

4.4 Alignment with the regulatory framework

By allowing efficient constraints, 'Removing constraints when efficient' is aligned with the broader regulatory framework. The National Electricity Market (with respect to load) is not designed to ensure uninterrupted electricity supply, for example:

- network reliability is underpinned by an assessment on whether the cost of reliable supply outweighs the benefits to consumers from it, which is based on the Value of Customer Reliability
- the generation reliability standard is set to 99.998%, recognising that the cost to ensure no generation shortfalls exist outweighs the benefit.

In reaching the view that some constraint may be efficient, we also had regard to the AER's reasoning in respect to Powercor's 2016–2020 regulatory period forecast for solar enablement, where the AER stated:[21]

> *'while we recognise that Powercor does "does not wish" to implement restrictions to customer connections because it may limit customer PV generation exports to the grid, the cost to a customer in limiting PV exports may be a magnitude less than the cost of installing or replacing a voltage regulator on the distribution system. Powercor has not performed any economic cost-benefit analysis of whether the long-term benefits to customers from investing in new voltage regulators will outweigh the costs from imposing restrictions on customer' solar PV voltage output during times of high voltage rises on the network*.'

Our approach now performs the cost benefit analysis that was sought by the AER.

4.5 The mechanism for managing constraints—dynamic control

We also received strong support for developing the foundations to dynamically control inverters. This requires developing a Distributed Energy Resources Management System (**DERMS**) which collects the network data from our AMI meters to understand and manage network constraints. While under either a dynamic approach or an uncoordinated approach (where customers experiencing the highest voltages trip off first and completely) result in constrained solar, the advantages of dynamic control include:

- being able to ramp down exports among customers along the same circuit more equitably rather than inverters experiencing high voltages tripping off and others not
- provide advanced warning of constraints and potentially enabling customers to use more of their solar in-home during those times
- as virtual power plants (**VPP**) become more mainstream it will be increasingly important for VPP operators to be have advanced notification of constraints.

In light of customer feedback and the benefits, we are proposing to develop the foundations of a DERMS and the capability for inverters to be controlled (not necessarily by us) as part of the Digital Network business case.

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21 CP ATT208: AER, Final Decision, Powercor distribution determination 2016 to 2020; Attachment 6 – Capital expenditure, May 2016, p. 62.

4.6 From whom costs are recovered

As mentioned, in our Option Paper we also considered options for recovering the cost of enabling solar including:[22]

- connection charge—an upfront charge paid by customers seeking to export solar
- 'quasi export tariff'—a reduction to the Feed in Tariff received by solar customers
- tariffs—spread across all customers.

When asked about enabling more residential solar on our network, customers and stakeholders had a preference that the cost is paid for by those connecting solar (65%). This was also the view from consumer advocates representing financially vulnerable customers.

On balance, we have opted to spread the costs among all customers on the basis that:

- solar is now a mainstream trend and the electricity framework is designed to spread such costs across all customers. In decisions for other distributors, the AER has accepted proposals to spread the costs, indicating the AER considers this is reasonable.
- the Solar Homes policy design suggests the Victorian Government is supportive of spreading the costs and benefits of solar among all Victorians.
- the 'wholesale fuel cost reduction' and 'carbon reduction' benefits from solar that we have quantified are shared by all customers. Other non-quantified benefits such improved environmental outcomes (e.g. air quality) and efficiencies in electricity market operations from new markets are also shared benefits. On this basis, sharing costs is appropriate.
- our customers shared with us their vision for the future being greener, and using technology to achieve this vision. When asked about solar, they indicated they want the broader benefits of solar shared across communities. Regional and local Renewable Energy Roadmaps supported by councils, the Greenhouse Alliances and communities are also strongly supportive of solar and sharing the social benefits of community energy. They are using crowd funding and group investment strategies to spread the costs of solar across communities. Support for spreading the benefits of solar indicates the costs should be spread.
- the price impact of this program is relatively small in the context of the overall costs of operating a distribution network, and in the context of overall network price decreases we are proposing the price effect will be lessened.
- there is uncertainty whether connection charges are allowed by the Rules and 'quasi export tariffs' could only be implemented by the Victorian Government or Essential Services Commission (**ESC**).

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[22] These options are outlined in more detail in our Options Paper.

5 Solar Enablement program

We developed a detailed modelling approach based on over 38 billion actual data points that we have collected through our AMI investment to give effect to the recommended option. Through this approach we have been able to determine how often and the amount of solar that: is currently constrained; will be constrained each year if we make no investment in the network; and if we invest to enable solar.

This detailed model has allowed us to maximise the net benefits of our investment program—that is, we will only remove constraints where the value of the solar unlocked exceeds the cost of investing in each site. It has also enabled us to ensure we target our investment to unlock the most solar for the least cost.

5.1 What we will deliver

Under the recommended option we will:

- enable all customers to connect solar
- enable 5kVA solar systems available for export for the large majority of customers[23]
- remove solar constraints where it is efficient to do so; where the benefits to customers outweigh the costs
- assist those customers where it is uneconomic to remove constraints to get the most out of their solar.

While our customers now expect to be able to export solar, affordability and reliability still rank as the most important issues. This has played a central role in our approach of only removing constraints where economic, but it means we cannot enable more exports for customers connected to transformers 50kVA and below. The cost of upgrading these sites is high relative to the exports they can accommodate meaning these sites cannot pass an economic test.

It is important to us, however, that to the extent possible we improve all customers' solar experience. Therefore, we will be providing information to these customers on ways for them to improve the value of their solar such as by installing batteries. We will also be targeting the initiatives from our Digital Network program toward these customers including helping them to shift hot water and pool pump loads to periods of high solar generation/export. Our existing eConnect portal, used for applying for solar connections, will also continue to provide these customers with upfront notification on whether they will be export restricted meaning they will not invest in solar based on an incorrect expectation.

5.2 Ensuring we only undertake targeted and efficient investment

5.2.1 Determining the efficient amount of solar to unlock

Our approach to find the efficient amount of solar to unlock is outlined in appendix B. In summary:

- for each of our 4,200 transformers, with AMI meters we took a voltage read every 15 minutes from 2018/2019. This enabled us to understand how often local voltages rise to levels that result in solar constraints and hence how much solar electricity is currently constrained.

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23 At our deep dive forum we presented modelling results assuming all new solar customers export 5kVA. Our customers pointed out, however, that most solar customers export less than this. Therefore we have modelled new customers to export a maximum of 3.1kVA (being the maximum amount our existing customers export on average) ramping up to 5kVA in 2025 (the maximum capacity allowed for export under our MSOs). Customers are now installing more panel capacity than their inverter size to maximise their solar output and we are seeing more customers exporting the full 5kVA. This modelled approach means that we will accommodate 5kVA solar customers that request it but recognise not all will.

- we applied the solar forecast to each of our transformers (i.e. we developed a forecast number of solar connections for each transformer).
- we conducted power flow modelling to determine the voltage rise that each new solar connection creates. In so doing, we assumed that each new connection has volt-var settings applied, which reduces the voltage rise associated with a connection, noting the AER approved these settings in 2019.
- applied the resultant voltage rise to the distribution of current voltage reads (from point 1) to determine how often (and how much) solar would be constrained each year as more solar connects.
- for each transformer we performed a cost benefits analysis to determine whether it is economic to remove the solar constraints. To perform this we:
  - engaged Jacobs to determine the value of solar energy by modelling the wholesale fuel cost reduction and carbon emission reduction benefit from solar
  - applied the value of solar to the amount of solar electricity constrained each year
  - compared the Net Present Value (**NPV**) of the solar electricity that would be constrained to the average cost of remediating a constraint to assess whether it is economic to unlock the constrained solar. This NPV analysis is performed for each year to determine the optimal timing of the investment. Only sites that were NPV positive are included in the forecast.

We do not believe this level of detailed modelling to assess the solar hosting capacity of the network has been undertaken before.

Jacobs has reviewed our model to determine whether it correctly performs the functions described. Jacobs found:[24]

> *Overall the code is well written, and based on the tests conducted by Jacobs and as per the scope of work…the Python code runs according to the specifications outlined by VPN. Furthermore, the functions in general contain a good level of data checks to ensure that calculations are only performed on numeric variables, that no division by zero is encountered and that infinite loops are avoided.*

5.2.2 Determining the efficient solution

We also used AMI data to pinpoint the most efficient solution to addressing constraints. In summary, and from least cost (and first preference) to highest cost to addressing a solar constraint:

- in 2019 we updated our Model Standing Offer (**MSO**) requiring new solar customers to apply new inverter setting which reducing the voltage impact of solar. These settings are:
  - volt-var settings—sets inverters to provide dynamic reactive power output, which absorbs some of the voltage rise from solar exports
  - volt-watt settings—sets inverters to reduce real power export once specified voltage limits are reached, to reduce some of the voltage rise from solar exports.
- included the impact of a Dynamic Voltage Management System (**DVMS**). This allows us to remotely and dynamically adjust voltages at the zone substations, meaning we can lower voltages at peak solar times and

[24] CP ATT055: Jacobs, Solar Enablement review of Python code, 25 November 2019, p. 21.

then increase them again later. A DVMS has already been implemented within our United Energy network and has proved to be successful in accommodating more solar at a low cost.

- considered (through data analytics) whether each transformer reaching a constraint can be tapped down.
- identified whether a network augmentation is required and will generate net benefits to customers. The augmentation solution and cost is based on the last three years of supply quality works undertaken across our network.

As mentioned, a key component to enabling solar is new inverter settings and in our analysis we have presumed these will be applied. We have modelled voltage rise based on 100% compliance of new solar systems. If installers fail to apply these settings, voltage rises will be significantly higher than forecast and customers will experience more constraints. Therefore we will be implementing a monitoring and compliance program, which is necessary based on our current experience of solar non-compliance and on the discussions with other distributors that have implemented these settings. This program is discussed more in B.4.

5.2.3 Ensuring no overlap between our programs

We have been careful to ensure the investment proposed under this business case is not included elsewhere in our proposal. Our current solar policy, whereby we prevent solar export capability if the connection would create a material voltage constraint, helps ensure that solar driven investment is not included in our historical expenditure or forecasts based on historical expenditure.

The investment for maintaining supply quality (included in our augmentation proposal and embedded within our operational base year) is based on historical expenditure and is typically needed to manage thermal transformer overloading arising from load growth of existing and new customers. It is also used to manage harmonics, flicker and load driven (low and high) voltage issues. These issues and the investment required to address them will be required irrespective of our solar enablement program. The supply quality forecast amounts to approximately $1.5 million per year. This would be inadequate for enabling solar on the network and does not address this need.

We recognise it is conceivable that supply quality works and solar enablement works will be required at the same location—meaning only one investment is needed. However with 4,200 transformer sites on our network potentially requiring works, a supply quality program that addresses 23 issues per annum (on average over 2016–2018), and the solar enablement program addressing 64 sites on average per year, the chance of these programs overlapping is very minimal.[25]

5.3 Operationalising Solar Enablement

This program determines the efficient level of investment in our network to enable solar. Our Digital Network initiative (in a separate business case) will help us to realise these modelled efficiencies to the maximum extent as the program is operationalised.[26] For example:

- balanced phases—when modelling voltage rises, we have assumed that solar will be balanced across phases (see section B.1.4). The Digital Network initiative will allow us to monitor and manage the phases on which solar connections are made. Without this, our forecasts will underestimate the locational voltage rise, meaning our investments may unlock less solar than modelled and/or increase the program costs.

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[25] We do not yet know the locations supply quality issues will arise.

[26] CP BUS 7.08 - Digital Network - Jan2020 - Public

- real time voltage rise—as solar connects we will be able to see the resultant voltage rise in real time and use this information to plan works in a timely and efficient way. Determining locational voltages (as done in this business case) is currently a manual process that cannot be monitored continuously.
- full LV network visibility—we do not know the conductor type in every location of our network. The Digital Network initiative will provide this information, which will enable us to plan the works outlined in this business case more accurately, ensuring we only undertake works where it is efficient to do so (as modelled).

As a result, the Solar Enablement and Digital Network programs are complementary but address different needs.

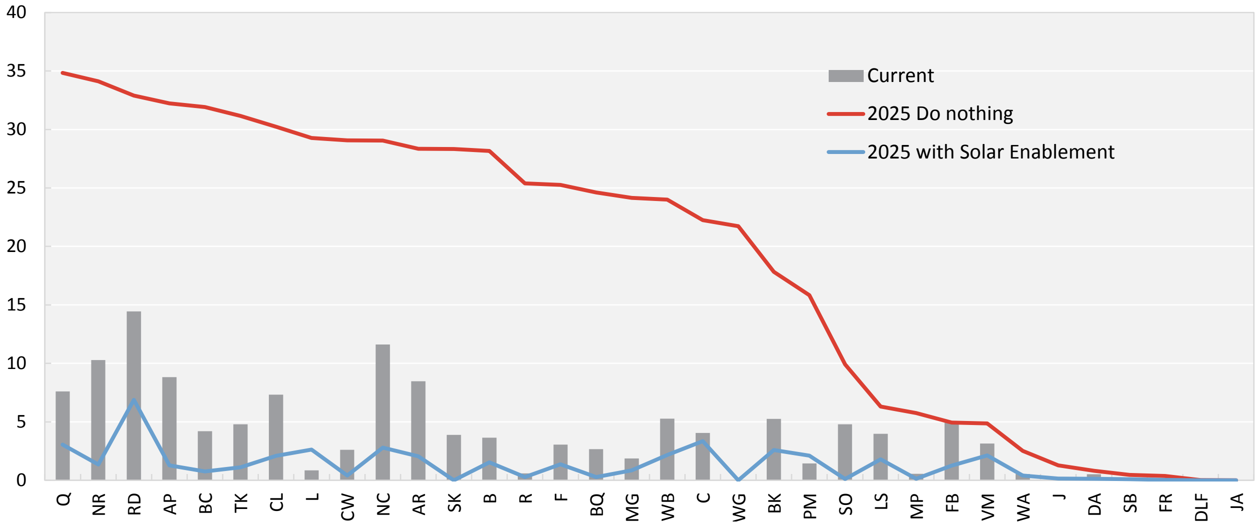
6 Results

To meet the identified need of this business case, we have determined the efficient level of solar constraint. The following results are based on the transformers over 50kVA which are subject to cost benefit analysis.

6.1 Solar constraint results—customer impact

We have aggregated our transformer level analysis to each zone substation on our network. Figure 10 shows the percentage of daylight hours for which solar is tripped now, in 2025 if we do nothing and in 2025 after this Solar Enablement program is implemented.[27] The zone substations are ranked from those experiencing the most tripping in 2025 to the least.

Figure 10 Solar constraints by zone substation (percentage of daylight hours)



Source: CitiPower

The red line indicates the time which solar is forecast to be constrained in 2025 if we undertake no action to accommodate it. By 2025 the average customer on 59% of our zone substations are expected to experience constraints more that 20% of the time.

The amount of constrained solar presented in figure 10 is inconsistent with our customers' expectations for reasonable use of their solar investment. It is also inconsistent with the Victorian Government's policy to help customers take control of their bills and tackle climate change. And importantly, it is more than the efficient level of constraint; that is, all customers would be better off with fewer constraints.

The blue line in figure 10 represents the outcome after our Solar Enablement program and the efficient level on constraint. After our program, the average customer is expected to face solar constraints for 2.3 days of the year.

The targeted nature of our investment is illustrated by considering the capital investment under our program needed to remove constraints (distance between the red and blue lines in figure 10) and the cost should we attempt to remove all constraints (the area underneath the blue line). This is shown in the table below.

[27] Some customers on these zone substations experience more and less tripping than this average.

Table 3 Value of capital investment ($ 000, 2019)

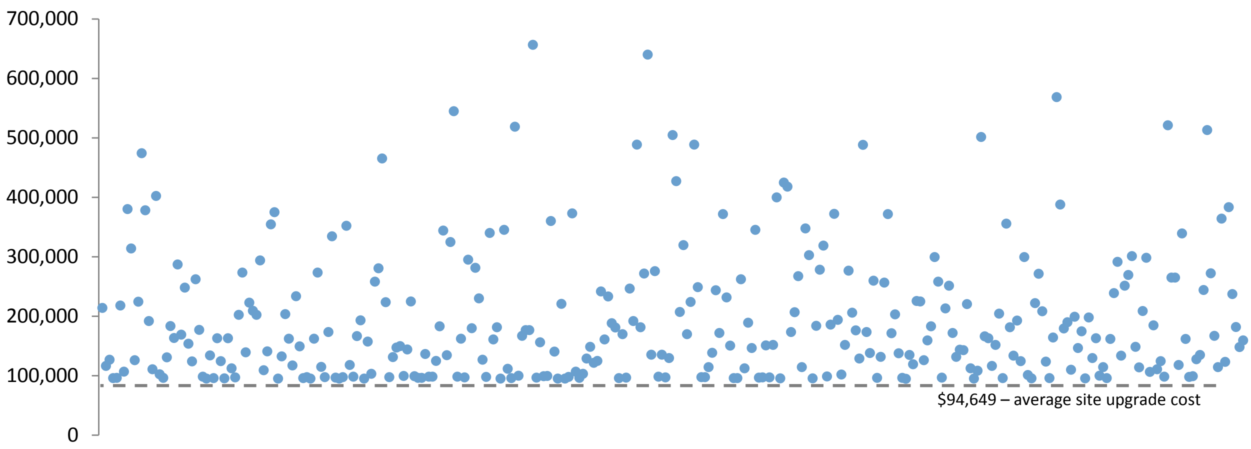
Item	$, 000
Our Solar Enablement program, capital investment	30,193
Remove all solar constraints	95,690

Source: CitiPower

Using our AMI data we are able to unlock as much solar as possible for the least cost.

Figure 11 is a scatter plot of the present value of benefits from performing a network augmentation on each transformer from our program. Each point is a transformer upgraded under our Solar Enablement program—its height is the present value of benefits.

Figure 11 PV of benefits from augmenting each site



Source: CitiPower

The present value of benefits generated from each transformer exceeds the average cost of performing a network upgrade to enable solar. Typically, larger transformers with more solar customers and which face more potential constraints have higher benefits from the Solar Enablement program.

This figure shows that net benefits are generated from each proposed augmentation and demonstrates that the net benefits are maximised:[28]

- if we were to undertake one additional transformer augmentation, the cost of that augmentation would exceed its benefits (i.e. it would be under the line in figure 11)
- if we were to undertake one fewer transformer augmentation, one of the existing transformers which generates net benefits from being augmented would be lost (i.e. one transformer would be removed from figure 11)

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28 We acknowledge that actual outcomes will differ from the modelled result, which is true of any model. However, the modelling approach leads us to maximising net benefits.

The total quantified benefit from this program (i.e. the sum of each transformer's benefits shown in figure 13) is shown in the table below.

Table 4 Present value of benefits ($ 000, 2019)

Item	$, 000
Present value of total benefits	62,088

Source: CitiPower

6.2 Solar Enablement investment

Our program maximises the net benefits to customers. The NPV of our programs is outlined in the table below.

Table 5 Net present value of the Solar Enablement program ($ 000, 2019)

Item	PV costs	PV benefits	NPV
Present value ($ 000)	29,961	62,088	32,126

Source: CitiPower

Targeted investment is required to implement the Solar Enablement program. Information on the cost build up is provided in appendix C. A summary of the investment profile is outlined in the table below.

Table 6 Investment profile ($ 000, 2019)

Item	2021/22	2022/23	2023/24	2024/25	2025/26	Total
DVMS	1,051	-	-	-	-	1,051
Tapping	170	151	191	92	86	691
Network investment	6,342	5,774	6,058	5,963	6,058	30,193
Compliance program	158	104	110	47	40	460

Source: CitiPower

This results in an incremental increase in operational investment from our 2019 base year as outlined in the table below (this is the sum of the tapping and compliance program costs from table 6). This step change is required to deliver the net benefits described in this business case.

Table 7 Operational investment step change ($ 000, 2019)

Item	2021/22	2022/23	2023/24	2024/25	2025/26	Total
Step change	329	256	301	139	127	1,151

Source: CitiPower

7 Summary of attachments

The key attachments that support this business case are:

- Solar enablement model available at CP MOD 6.02. This model outlines the costs and benefits of the solar enablement business case.
- Oakley Greenwood, Profiling uptake of solar PV, available at CP ATT004. This report outlines the solar forecast we have used.
- Jacobs, Market Benefits for Solar Enablement, available at CP ATT054. This is the report that outlines the approach to valuing solar electricity.
- Jacobs, Solar Enablement review of Python code, available at CP ATT055. This review confirms that our model operates in accordance with the specifications outlined.

A Option analysis

A.1 Option 1— no action to enable solar

Under this option we would allow all customers to connect export capable solar but not ready the network for it.

A.1.1 'Unmitigated tripping'

As solar penetration increases, customers will experience more constraints. Indeed, inverters may trip in a continuous cycle—as inverters compete with each other to export the network voltages will rise, inverters will trip, reset, and then push up voltages again.

We sought feedback on this option in our Option Paper. This option was not supported because the high levels of tripping undermine the value of customers' solar investments.

Also this option is not underpinned by economic analysis. There is no assessment of whether allowing customers' solar to regularly trip is in their interests. As such, this option does not maximise customer benefits or result in efficient outcomes.

A.1.2 'First come first served'

The 'first come first served' option is where we would establish export restrictions on transformers when a voltage constraint develops. If solar connects to transformers with headroom, exports will be allowed but once thresholds are met, the inverters of subsequent solar customers are required to be set to 'no export'.

We sought feedback on this option in our Option Paper. This option did not receive customer support due to its inequity.

Also this option is not underpinned by economic analysis. The option sets technical thresholds for limiting solar based on the network's current hosting capacity, without considering the costs and benefits of the solar i.e. it may be economic to undertake works to enable more solar to connect. As such, this option does not maximise customer benefits or result in efficient outcomes.

A.1.3 Dynamic control

Where constraints occur, we received strong customer support for constraining customers via dynamically controlling inverters.

Dynamic control does not change the amount of solar that will be constrained—when voltage levels reach the threshold they will either be constrained naturally or need to be constrained dynamically by ramping down solar output. However, there are advantages of having dynamic control capability as discussed in section 4.5. The costs and benefits of this capability are included in the Digital Network business case.

A.2 Option 2—behavioural change

A.2.1 Tariff reform

Under this approach we would implement tariffs to encourage customers to use more electricity during high solar generation periods to minimise exports and network voltage constraints.

We engaged extensively with other Victorian distributors, the industry and customers before setting our tariff structures. This engagement is documented on our Talking Electricity website.[29] Customer feedback focussed on using tariffs to reduce peak load driven costs and remove cross subsidies rather than enabling more solar. We

29 Talking Electricity <https://talkingelectricity.com.au/>

consider this appropriate as tariffs targeted at accommodating solar are unlikely to be effective on our network because:

- there is no tariff that would clearly be suitable. For example, encouraging people to use electricity at peak solar export periods (10am-3pm) to enable more solar—such as SAPN's 'solar sponge' tariff— is not fit for purpose on our network can experience peak load at this time
- currently we are unable to apply such tariffs in Victoria, and it is not clear if/how this will change over the 2021–2026 regulatory period
  - any such tariffs are likely to be optional, meaning the customer uptake could be minimal
- the customer response to solar targeted tariffs is likely to be marginal:
  - tariffs may encourage efficient use of the network from a load perspective and/or an export perspective but this behaviour change is unlikely to be sufficient to remove the voltage issues caused by solar
  - retailers may not pass on the tariff structure to customers/may not pass on the full strength of the tariff
  - customers' response to tariffs will be impacted by their understanding of it
  - with a larger price signal customers are more likely to respond, however, this also increases the likelihood of bill shocks

While tariffs is potentially a low cost (from a network perspective, but not necessarily when considering the cost of customers' behavioural change) way to enable more solar, it does not necessarily lead to the efficient level of solar overall. That is, it may be efficient to enable more solar than the amount delivered by tariffs and so this option could only be used to complement another option. In response to our Options Paper, our customers also considered tariffs could complement another option for enabling solar.

At this stage, there is considerable uncertainty as to what any tariff reform would look like and the take-up/effectiveness of it.

A.2.2 Quasi-export tariffs

The FiT could be reduced which would lessen customers' financial incentive to export and would instead seek to use as much solar themselves, for example by orientating their panels to ensure maximum production when they are at home (typically in the evenings) and purchase batteries to store solar for when its needed.

Only 20% of customers supported this option and most ranked it 5th out of the 7 options presented. It also is not consistent with our customers' views that they want to have and export solar to lower their bills and achieve greater energy independence as it would lessen customers' payments from solar and the amount of solar electricity generated.

This approach would lessen customers' incentive to install solar which is not in line with the Victorian Government's Solar Homes policy.

This option could be implemented by the Victorian Government and Essential Services Commission (Victoria).

A.3 Option 3—removing constraints

A.3.1 Alleviate constraints when they appear

Under this option new solar customers could connect with export capability. Once the maximum voltage for customers on a transformer reaches the level which causes solar constraints, we would undertake works to remove the export.

This is the approach we presented at our deep dive forum with customers. We presented a number of scenarios such as:

- removing all constraints
- removing constraints for customers on transformers 50kVA or above only
- removing constraints for most, but not all of the time (i.e. allow some periods of tripping, but the amount of tripping could not be quantified under the model we developed to support this approach)
- allowing different capacities of exports such 5kVA and 3.1kVA
- various combinations of the above.

We engaged Jacobs to value the solar enabled (discussed more in section B.3.1) to compare to the costs to determine whether there were net benefits.

In response to our Options Paper, this option was supported by our stakeholder; it ranked as the option that most likely 'make sense' to enable solar.[30] When asked stakeholders to rank the 7 options presented, 60% of customers also selected this as their first preference.

This approach was based on an economic analysis in so much that it compared the costs of different scenarios to the benefits. Fundamentally, however, this approach could not determine the optimal solution. While it could determine that removing some amount of tripping would result in net benefits, we could not quantify the amount of tripping that would maximise customers' benefits i.e. the efficient level. Therefore we developed another approach as discussed below.

A.3.2 Removing constraints when efficient

Under this approach new solar customers would be able to connect with export capability. We would determine how often solar would trip and if the value of the tripped solar exceeds the cost of removing the constraints, we would do so.

This approach allows us to determine the efficient outcome. It recognises there is a level of tripping which is efficient (i.e. when it is more costly to remove than to allow the tripping to continue) and conversely that there are instances when it is efficient to remove a constraint. The approach is outlined throughout this business case.

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30 This was presented as option 7 in the Options Paper.

B Forecast approach

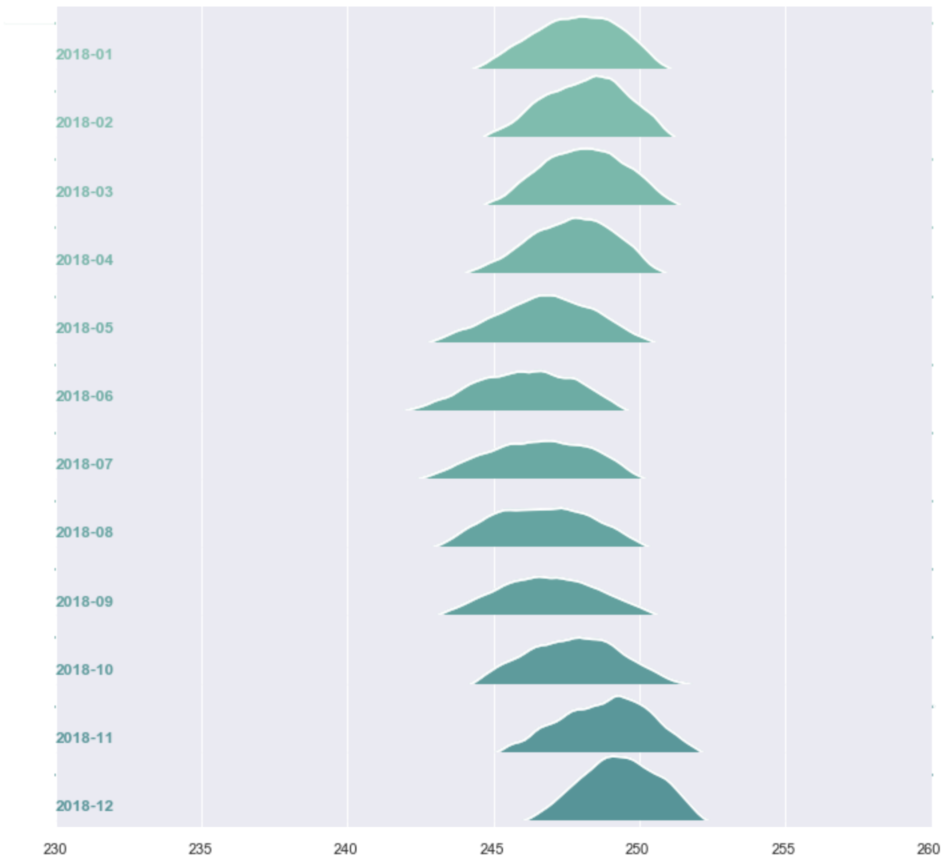
We have developed a model that uses over 38 billion actual AMI voltage readings to examine how often solar will trip on our 4,200 transformers to 2029. We have then compared the cost of removing a voltage constraint with the benefits as measured by the value of solar energy.

B.1 Determining the amount of solar tipping

B.1.1 Meter data—starting point

For each of our National Meter Identifiers (**NMI**), we gathered a voltage reading every 15 minutes from 2018/2019. Figure 12 shows the distribution (or histogram) of 15 minute voltages reads for each NMI on a single transformer for 12 months.

Figure 12 Actual 15 minute voltage readings on a single transformer



Source: CitiPower

From this we found the current amount of solar tripping across our network by counting the reads (with solar) above the threshold at which inverters trip. This also provided the starting point for the forecast of solar tripping.

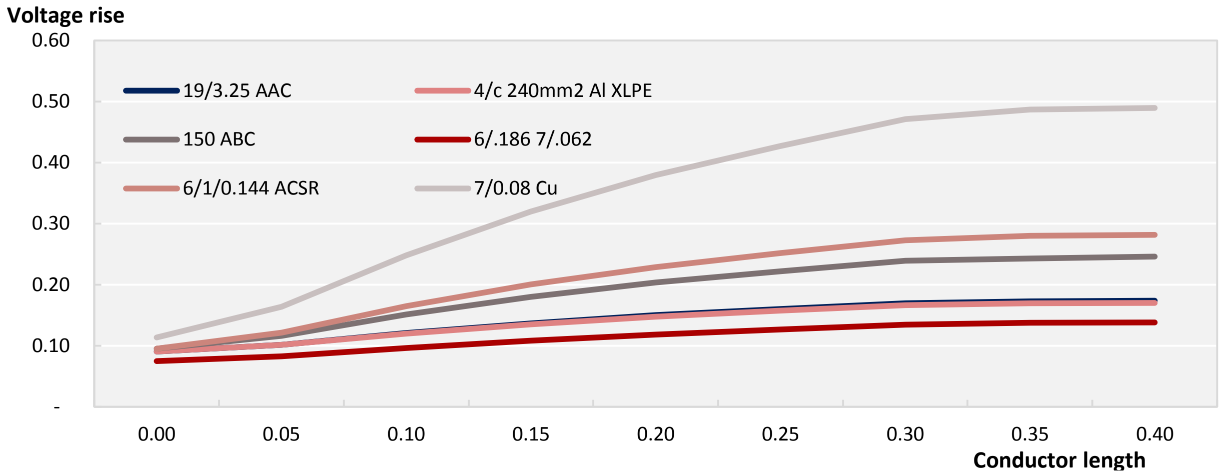
B.1.2 Forecast solar

From the solar forecast undertaken by Oakley Greenwood discussed in section 2.2, we removed the component of commercial solar that will connect.[31] After making this adjustment to the forecast we distributed the remaining solar forecast, which was undertaken by Oakley Greenwood at the Local Government Area (**LGA**) level, to each distribution transformer based on customer numbers, historical locational solar growth and saturation limits.

B.1.3 Voltage rise

We undertook load flow modelling to determine the voltage rise from new solar connections. In so doing we modelled the voltage impact of new solar our different conductor types and for different conductor lengths. The modelling assumed all new customers have volt-var inverter settings applied.

Figure 13 Voltage rise by conductor type



Source: CitiPower

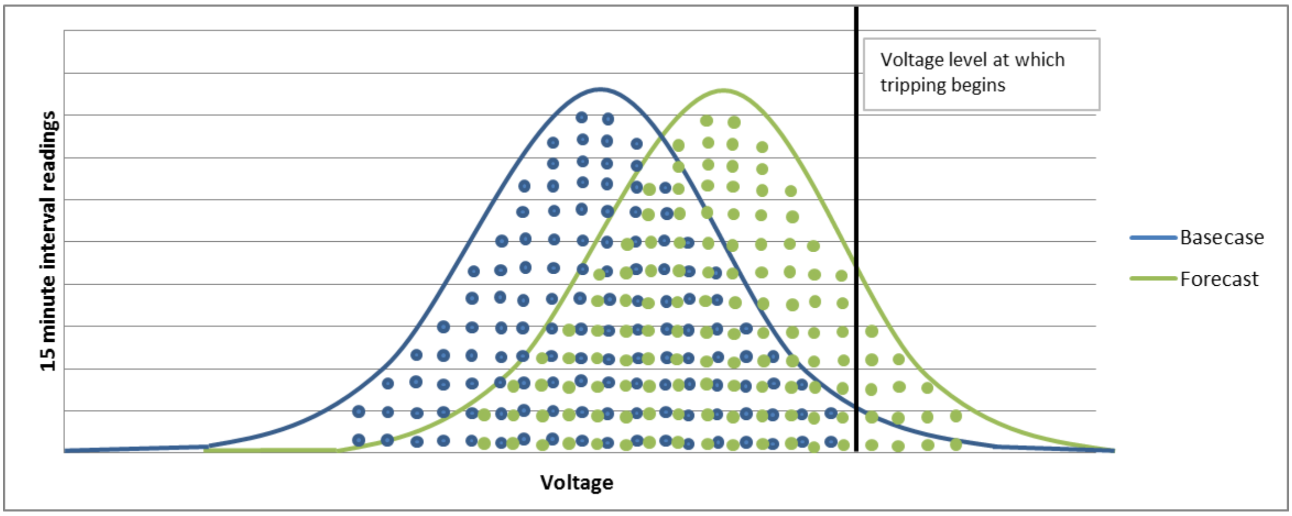
We applied the relevant voltage rise to our transformers based on the amount of solar expected to connect (as above). The voltage rise per customer was based on the actual conductor type and used the mid-point distance of the actual conductor (i.e. on average customers were assumed to connect halfway along the conductor length).

B.1.4 Application of voltage rise to voltage distribution

We shifted the distribution of actual voltage readings based on the voltage rises and solar forecast discussed above. From this we forecast the percentage of time that exceeds the tripping limit. Figure 14 illustrates how the solar forecast has been applied to the distribution of actual voltage readings to forecast the amount of constrained solar.

[31] This business case is directed at residential solar. Commercial solar customers fund to removal of network constraints when they connect.

Figure 14 Forecasting future tripping



Source: CitiPower

In applying the voltage rise, we counted the number of circuits on each transformer and applied solar evenly across them. We also presumed our phases are perfectly balanced. We only count a voltage rise after we have evenly allocated solar to each phase on each circuit. Only applying voltage rises once customers have been allocated in this way and presuming phases are balanced are both conservative assumptions under which we are likely to be underestimating the voltage rise associated with solar.

Because solar produces different amounts at different times, we found the average daily network generation curve for the summer, winter and shoulder seasons based Bureau of Meteorology solar irradiance data. We applied the percentage of time solar exceeds the tripping limit to this solar generation curve to determine the amount of constrained solar.

New customers are modelled to export a maximum of 3.1kVA in 2019—being the maximum amount our existing customers export on average—ramping up to 5kVA (in a straight line) in 2025. This approach is in response to customer feedback that pointed out most solar customers export less than the maximum inverter size they can connect under our Model standing Offer (**MSO**) or 5kVA. The ramp up is because customers are now installing more panel capacity than their inverter size to maximise their solar output and we are seeing more customers exporting the full 5kVA. This modelled approach means we will accommodate 5kVA solar systems for customers that request it (in accordance with our MSO) but recognise not all customers will.

B.1.5 Setting the voltage threshold at which solar trips

To set the voltage threshold used in the model to determine when tripping occurs, we first considered the impact of a Dynamic Voltage Management System (**DVMS**), which we are proposing as part of this business case.

A DVMS is able to change voltage set points at zone substation in response to changes in voltage levels. Currently we can undertake this manually, but solar exports vary regularly and it is not possible to manually monitor voltages and change set points continuously. As such, we currently only use this functionality occasionally for system security.

Transformers connected to a zone substation can experience different voltages at the same time, for example due to the number and type (solar or not) of customers connected, the conductor type and transformer tap settings. Therefore to analyse the impact of a DVMS, we considered the voltages on each transformer connected to each zone substation and whether, at times of high solar exports/voltages, the zone substation voltages could be lowered without some transformers voltages being pushed below the Code.

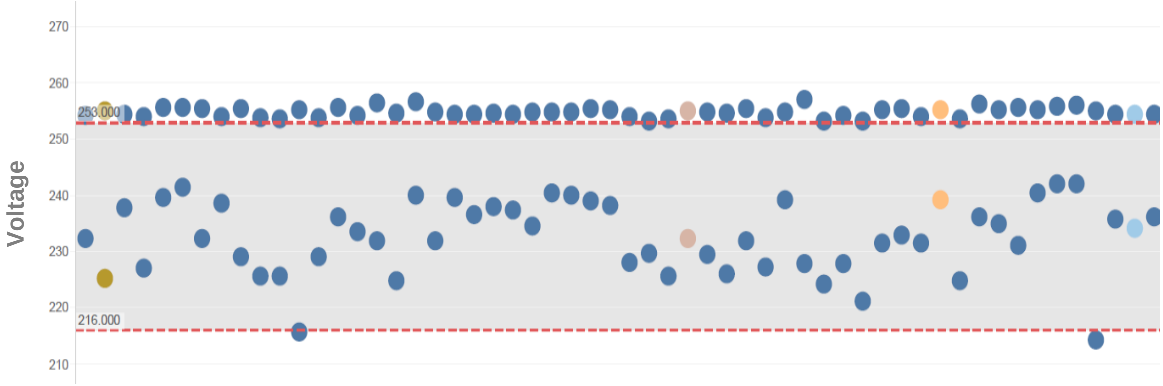
To apply the impact of DVMS in our modelling, we have set the threshold at which solar will be constrained in our model higher than the actual level (i.e. we have reduced the amount of forecast constraints in our modelled outcomes because DVMS will have this affect once operational).[32] We have valued solar that is lost once inverters trip rather than also including the reduction to active power output from the new inverter settings.

B.2 Identifying the least cost way to address a constraint

As discussed, we first considered the impact of new inverter settings and implementing a DVMS as these are both low cost ways to enable more solar.

We then considered whether voltages could be reduced by tapping transformers down as this is the next least costly option. To determine whether a transformer could be tapped, we examined the minimum voltages experienced by customers on that transformer. If the minimum voltage could be lowered while remaining with the minimum voltage threshold outlined in the Code, we allowed for the transformer to be tapped. This analysis is illustrated in the figure below.

Figure 15 Determining whether transformers can be tapped

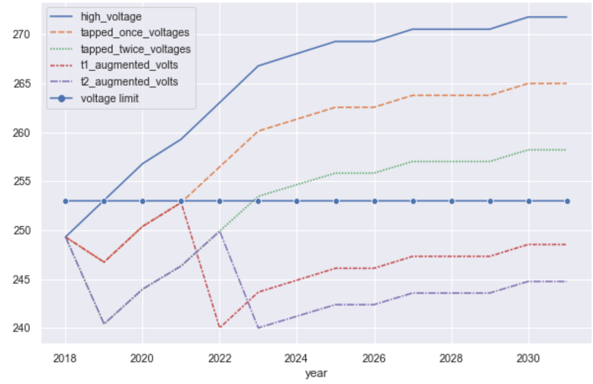


Source: William-Thomson transformer

Some transformers had sufficient headroom to be tapped multiple times, which was then allowed for in our model.

[32] The threshold set in the model to determine current constraints is set at 253V and to determine future constraints it is set at 255V (which is the equivalent of 253V once a DVMS is implemented). 253V is both the maximum voltage level outlined in the Code and the point where inverters are constrained. There is a voltage drop of up to 2% (AS/NZS 4777.1:2016, section 3.3.3) or 5V between the meter where we measure voltages and the inverter. 253V at the meter equates 258V at the inverter. Solar connected prior to 2020 trips at 255V and new inverters begin substantially ramping down from 253V and trips at 258V.

Figure 16 A transformer that can be tapped more than once



Source: Powercor, CitiPower, united Energy model

We have based the cost of tapping transformers on the average cost per site tapped 2018.

For sites that could not be addressed by the above option, we have forecast the need for a capital solution. Broadly, these fall into the following categories:

- low voltage conductor augmentation—this is implemented where existing conductors have high impedance, which in turn increases the effects of voltage rise.
- transformer replacement—a common method to address high volts on LV networks. This can be achieved in one or two ways:
  - installing transformers with the ability to 'buck' or lower volts at the secondary terminals
  - installing transformers of larger capacity. As the capacity of a transformer increases so does the amount of or current it can supply.

We have identified the nature of the augmentation solution and the costs based on the solutions and costs of undertaking augmentation work to address relevant supply quality issues over 2016–2018. This period ensured we had a representative sample of the types of augmentation works required to address supply quality issues. The average capital solution costs used in our modelling has been weighted by the historical number of projects. These costs are outlined in appendix C.

We are also investigating a number of alternative ways to accommodate more solar such as:

- network scale battery storage system—examining whether batteries located adjacent to the distribution transformer can be used to ease network demand and assist to integrate solar
- on-load tap changing transformers—we are in the process of reviewing these, however, at present the costs are higher than the other options available
- low voltage regulators—these can boost or buck the incoming line voltage. These are typically a high cost solution for the number of customers they can affect

- Faraday Exchanger—this technology has the potential to address the voltage issues present on LV network. This technology has not yet been proved in the context of an electricity network, however, we will monitor the outcomes of our sister company, UK Power Network's, trial.[33]

If these alternatives prove able to reduce voltages in a cost efficient manner, we will seek to adopt them over the regulatory period.

B.3 Applying the economic test

We have embedded a cost benefits analysis within the model for forecasting solar constraints to determine the efficient level of tripping.

B.3.1 Valuing of solar electricity

We engaged Jacobs to value the constrained solar energy and hence quantify the benefit from removing a constraint. We provided Jacobs with the baseline solar forecast (assuming no constraints) and the amount of solar energy constrained under a 'do nothing' scenario.[34] This was provided in half hour increments based on the solar generation curves discussed above. Jacobs undertook wholesale market modelling to determine the changes in fuel consumption and carbon reduction benefit arising through different patterns of generation dispatch in accordance with the AER's RIT-D. Jacobs report is attached.[35]

Jacobs determined the average value of solar energy to be $47 per MWh. This is a conservative estimate because it:

- is lower than the FiT of $120 per MWh set by the Essential Services Commission (Victoria), which represents a value of solar
- is lower than the value used by other distributors' in their solar business cases[36]
- focusses on the fuel cost rather than the wholesale price change of generation, with the former being lower

Included in the value we have adopted of $47 is the carbon reduction benefit because tackling climate change and providing a clearer future is a key reason for the Victorian Government's Solar Homes program.[37] If we were to exclude the carbon reduction benefit, we would be undervaluing the Victorian Government's policy by enabling less solar than is economically justified by the stated aim of the program.

On each transformer that we forecast to experience tripping, we multiplied the value of solar electricity by the amount of tripped solar to determine the total benefits that would be achieved from removing the constraint.

B.3.2 Cost benefit analysis

Within the model we compared the Net Present Value (**NPV**) of the energy value of solar (the product of the market benefits determined by Jacobs and the amount of constrained solar per transformer per year) to the

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33 There are also regulatory/ring fencing considerations as Faraday Grid's business model is to partner with distributors and share in revenues generated from the devices from providing services in ancillary markets.

34 This was done in aggregate for CitiPower, Powercor and United Energy on Jacob's advice. Included commercial and greenfield site rooftop solar.

35 CP ATT054: Jacobs, Market benefits for solar enablement , August 2019 .

36 SAPN, Houston Kemp - Estimating avoided dispatch costs and VPP, January 2019, p.16. Adopted a value of around $50 per MWh.

37 Solar Homes Victoria <https://www.solar.vic.gov.au/>

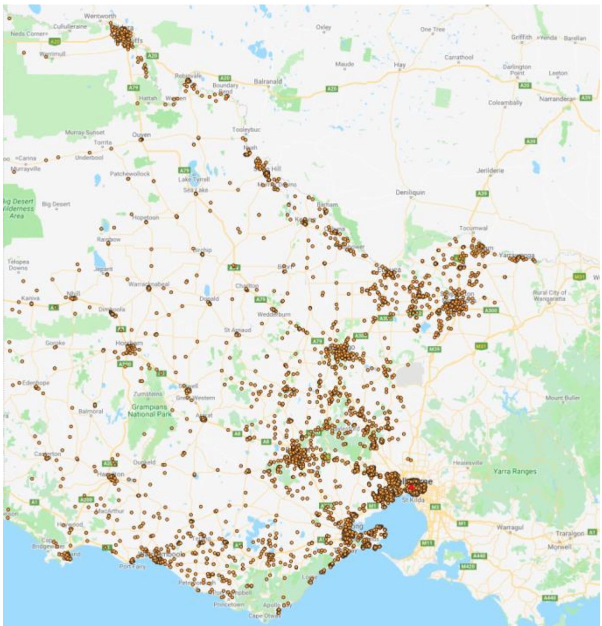
average cost of augmenting the site over 30 years.[38] This ensured we only propose expenditure when the costs are lower than the benefits customers will receive. The impact of DVMS and the transformer tapping investment were not included in the cost benefit analysis because the cost of these options is low; it will always be economic to tap a transformer to remove a constraint. Nevertheless the program is still NPV positive when these costs are included as outlined 6.1.

B.4 Monitoring and compliance regime

A key component to enabling solar is new inverter settings we have applied. If installers fail to apply these settings, voltage rises will be significantly higher than forecast in this business case and customers will experience more tripping. Based on our own experiences with non-compliance and that of other distributors that have already mandated new inverter settings, without any intervention we expect non-compliance with new inverter settings to be material. Therefore we are proposing a compliance program as part of this business case. In addition there are many ways in which customers are currently non-compliance, including installing larger capacity inverters than our MSO stipules, and not export limiting their installation when asked to do so. We expect this will continue.

The map below shows sites that have solar (or another form of export) that have not informed us, which is a requirement for connecting solar.

Figure 17 Unregistered sites with exports



Source: CitiPower and Powercor

Often customers are not aware of their non-compliance because it is due to their installer not following procedures. Nevertheless, these non-compliances make it more difficult to plan the network and ultimately reduce the amount of solar produced by complaint installations.

We have forecast the monitoring and compliance costs based on the:

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38 This is a conservative estimate of the benefits as network assets have a longer life.

- cost to implement remote monitoring using our existing information management systems
- current rate of non-compliance where customers exports exceed their registered inverter size (being 5% of solar customers) and assuming it takes one hour on average to rectify the non-compliance. This is a conservative assumption given we expect non-compliance with the new inverter settings to be much higher based on the experience of other distributors.

The forecast costs are outlined in appendix C and section 6.2.

C Cost build up

This section provides more detail on the cost build up for DVMS, network investments and the monitoring and compliance program.

7.1.1 DVMS

The cost build up for developing DVMS based on the work scope and costs from the United Energy DVMS rollout.

Table 8 DVMS investment build up ($2019, 000)

Item	Investment
Labour (incl. SensorIQ Config, IT/OT Integration Build, Testing)	2,004
Software (Integration Software IT/OT, New DMS Integration software module)	500
Hardware (DVMS Engine, Integration Zone, Secured Analytics Gateway)	1,000
Percentage allocated to CitiPower	30%
Total	**1,051**

Source: CitiPower

7.1.2 Network investment

The network investment cost is based on a weighted average of relevant supply quality costs over the past three years. By weighting these costs by the type of works undertaken, the forecast of works required to remediate solar constraint sites is based on the actual characteristics of our network. The cost build up is shown below.

Table 9 Capital investment build up ($ 000, 2019)

Year	Number of projects	Total cost	Average Cost
Low voltage augmentation			
2016	7	597.2	85.3
2017	9	896.5	99.6
2018	7	411.1	58.7
Transformer and augmentation			
2016	2	208.3	104.2
2017	6	835.7	139.3
2018	14	1,357.4	97.0
Transformer only			
2016	1	117.0	117.0
2017	2	119.9	59.9
2018	-	-	-
Total	**48**	**4,543.2**	**94.6**

Source: CitiPower

7.1.3 Monitoring and compliance program

The investment to deliver the monitoring and compliance program is outlined below.

Table 10 Monitoring and compliance investment ($2019, 000)

	2021	2022	2023	2024	2025	Total
Implementation and maintenance	84.6	14.1	14.1	14.1	14.1	141.0
Addressing non-compliances	73.7	90.2	95.8	32.7	26.4	318.9
Total	**158.3**	**104.3**	**109.9**	**46.8**	**40.5**	**459.9**

Source: CitiPower