Analysis of EMS Options for the VEU Program

Prepared for

Department of Environment, Land, Water and Planning

15 October 2019

Updated V2.0

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Contents

Basis of EnergyConsult Work

The work of EnergyConsult in connection with this assignment has been reliant on information and analyses supplied by third parties and the Department. We have performed research and analysis using this data and publicly available information drawn from a wide range of information services, output of analyses conducted by third parties, and other information which was available to use within the timeframe specified for the preparation of the report. This data was used in order to provide the Department with analysis which may be relevant to the requirements of the Department. The analysis also relies on a number of assumptions, both stated and unstated in the report, which are in turn based on our analysis of third party information.

EnergyConsult has not independently verified, nor can we accept any responsibility or liability for independently verifying, any of the information on which our work is based, and nor do we make any representation as to the accuracy or completeness of the information which has been used in our analysis. We accept no liability for any loss or damage which may result from the Department’s reliance on any research, analyses or information so supplied, nor from our report, research and analyses based on this information.

Executive Summary

The installation of and use of energy management systems and controls can provide significant opportunities for energy and emissions savings for the VEU program. This study has focused on the opportunities that will be able to scale of the period 2020 to 2025. The aim of this research is to examine the potential of Energy Management Systems (EMSs) to reduce emissions, which generally will mean lower energy use, or greater use of renewable energy behind the meter.

The products suitable for the residential sector and included in the analysis that are assessed as scalable over the period to 2025 are:

- Smart Thermostats
  - Ducted Natural Gas
  - Ducted AC
  - Split AC
- Lighting
- Pool Pump Automation
- Energy feedback reporting systems

Whole house energy management systems are not specifically included in the analysis as they would likely include a combination of the products and strategies listed above. The estimated savings for each of the products and services is shown in the table below.

Summary of estimated energy savings for Residential products/services

Product/Service	Estimated Energy Savings	
	Electricity	Natural Gas
Smart Thermostat NG Ducted	0%	10%
Smart Thermostat AC Ducted	10%	0%
Smart Thermostat AC Split	10%	0%
Lighting	10%	0%
Pool Pump Automation	65%	0%
Energy Reporting Feedback Systems		
IHD	6.6%	0%
App + Smart meter	4%	0%
App + IHD/Meter Interface	10%	0%

The use of building energy information and intelligent controls is examined within the business sector, largely focusing on the non-industrial segments (offices, retail, hotels, health and refrigerated cold food storage systems in businesses). These opportunities are generally labelled as energy management and information systems (EMIS), but the term is used very broadly and includes a range of opportunities, including:

- Energy information systems.
- Energy management systems for buildings, typically using energy information systems, but combined with actionable alerts or automatic control of energy using systems (HVAC, lighting, refrigeration), using the building management system (BMS).
- Energy management systems specifically targeting specific end uses and equipment.

The IEA have identified that improving the operational efficiency of buildings by using real-time data could lower total building energy consumption between 2017 and 2040 by as much as 10% compared with their Central Scenario, with the majority of this occurring the non-residential building sector(IEA, 2017).

The products included in the analysis assessed as scalable over the period to 2025 are:

- EMIS – Small – targeting small to medium energy users:
  - Basic – typically using premises level energy data from the smart meter.
  - Disaggregated – using circuit level energy data from meters installed at the switch board or in the site.
- EMIS/EMS – Large. Integrated controls and data analytics targeted larger buildings.
- Smart Thermostat/timers – targeting small to medium energy users.
- Refrigeration EMIS: small – targeting refrigeration systems (cabinets, walk in cool rooms) for small to medium energy users.

The estimated savings for each of the products and services is shown in the table below.

Summary of estimated savings for business products/services

Product/Service	Estimated Savings	
	Electricity	Natural Gas
EMIS - Small: basic	5%	0%
EMIS – Small: disaggregated	15%	0%
EMIS/EMS - Large	10%	10%
Smart Thermostat/timers	15%	0%
Refrigeration EMIS: small	20%	0%

1. Introduction

Objective

The objective of this work is to provide analysis and information on energy management options for households and small to medium enterprises (SMEs) for the Victorian Energy Upgrades (VEU) program. This report aims to provide technical data regarding the opportunities that exist now and in 2021-2025 for carrying out upgrades in residential or non-residential premises by installing or integrating software, digital technology or other products that manage energy usage behind the meter in a manner that leads to emissions reductions.

The analysis looks at the potential uptake of software, technology or products that manage energy consumption behaviour behind the meter for the period 2019 to 2025, to assist with the development of VEU targets.

Background and Scope

This report documents the results of the environmental scan of existing digital energy management products/systems which have the ability to scale effectively in the Victorian residential and SME sector in the period 2021 to 2025. It also discusses how such products reduce carbon equivalent emissions, and the influencing factors. A summary of the energy modelling for the VEU is also provided, along with the key inputs, assumptions and sources.

Scope

The project required an environmental scan of energy management software and products in households and SMEs including but not limited to:

- products that lead to behaviour change, such as In-Home Display (IHD) devices and apps
- distributed demand management products excluding solar panels and batteries, where individual installations of such products or the installation of a combination of such products results in energy reductions (assuming the existence of solar panels with or without battery storage at the premises)
- products that lead to maximisation of self-consumption of solar energy, for example, solar diverters which divert excess rooftop generation into electric resistance water heaters rather than feeding that energy into the grid, and other hardware based solutions
- products associated with automation of energy management
- products associated with 'smart home' automation

- products associated with automation of voltage optimisation
- energy management systems (particularly in commercial buildings).

The report's focus is on identifying existing hardware and software products which have the ability to scale effectively in the period 2021 to 2025 rather than theoretical future developments. The Department requires advice regarding:

- the types of products that may be suitable for households and SMEs
- the potential energy bill savings for households and SMEs
- how these products can reduce carbon dioxide equivalent emissions (for instance, emissions reductions may be delivered through providing behaviour change advice that encourages energy efficiency behaviour, by directly reducing energy usage or by supporting the growth and integration of self-consumption of solar at the premises, especially where there are export constraints to the grid)
- the quantity of carbon dioxide equivalent emissions (in tonnes) that can be attributed to the different types of use cases
- this may be the effect of installing a single product, a combination of products or an entire energy management system
- the likelihood such products will be installed for a given amount of incentive
- the pool of opportunity that exists in Victoria for households and businesses to install such products
- the rate of installation, production, sales (current and projected), of such products.

This data and model are used to update the Department's current model of the energy efficiency (and related) opportunities within Victoria.

Methodology

The methodology used for undertaking this research comprised of the following tasks:

- Data Collection, Preliminary Environmental Scan and Analysis Approach
- Prepare Analysis and Model of Energy Management Products/Systems
- Reporting.

The consulting team comprised of Paul Ryan (EnergyConsult) and Geoff Andrews (Genesis Now). Ken Guthrie (Sustainable Energy Transformation) provided a review of the hot water related research.

Additional work was undertaken to assess the maximisation of self-consumption of solar energy following the completion of the study. This is presented in this 2nd version of the studty report in Appendix B: EMS with BTM Strategies.

2. Methodology/Approach

This project draws upon desktop research, interviews with key stakeholders and modelling to meet the objectives. The key use of the desktop research and interviews is to provide supporting evidence for the key modelling inputs, identify the technologies/solutions that have potential to reduce emissions and scale over the period to 2025.

Interviews were undertaken with 8 stakeholders relevant to the topics, including NGOs, consultants and suppliers. Over 90 reports have been thoroughly reviewed to support the evidence base, particularly for determining potential energy/emission savings, influencing factors and the ability for technologies to scale.

Analysis Approach

The approach for determining the potential emissions reductions of the technology solutions over the period 2020 to 2025 is based on the Department's modelling framework. These include the following for each of the opportunities:

1. Determine the applicable Victorian energy user market that will be eligible or within the scope of the technology solution
    a. Size in terms of households, business buildings and floor space over the 2020 - 2030
    b. The energy use intensity (MJ/house, MJ/m^2) by fuel for each market segment and trends over 2020 – 2030
    c. Share of energy end use (lighting, HVAC, refrigeration etc)
2. Determine the addressable energy use for the technology solution, i.e., natural gas heating, AC, for smart thermostats.
3. Estimate the share of the market already installing the product and projections to 2030 under BAU
4. Calculate the potential total and annual maximum take up of the technology under VEU
    a. Estimate the installed costs of the technologies from the research
    b. Estimate the energy and emission savings, based on the research
    c. Using uptake rates functions derived for other Departmental models, estimate the annual take up. Take up rates are either dependent on the share of costs subsidised by the VEECS or the payback period after Victorian Energy Efficiency Certificates (VEECs) are applied
5. Calculate the pool of opportunity remaining, and the annual take up in terms of energy /emissions savings, VEECs and installations by market segment

The model uses the VEECs price that is derived from the models for all the VEU activities aggregated in a master model by the Department.

Details of the key inputs (market segment size, costs, etc) are provided in Appendix A: EMS Uptake and Impact Assessment. The model is provided to the Department, including links and references.

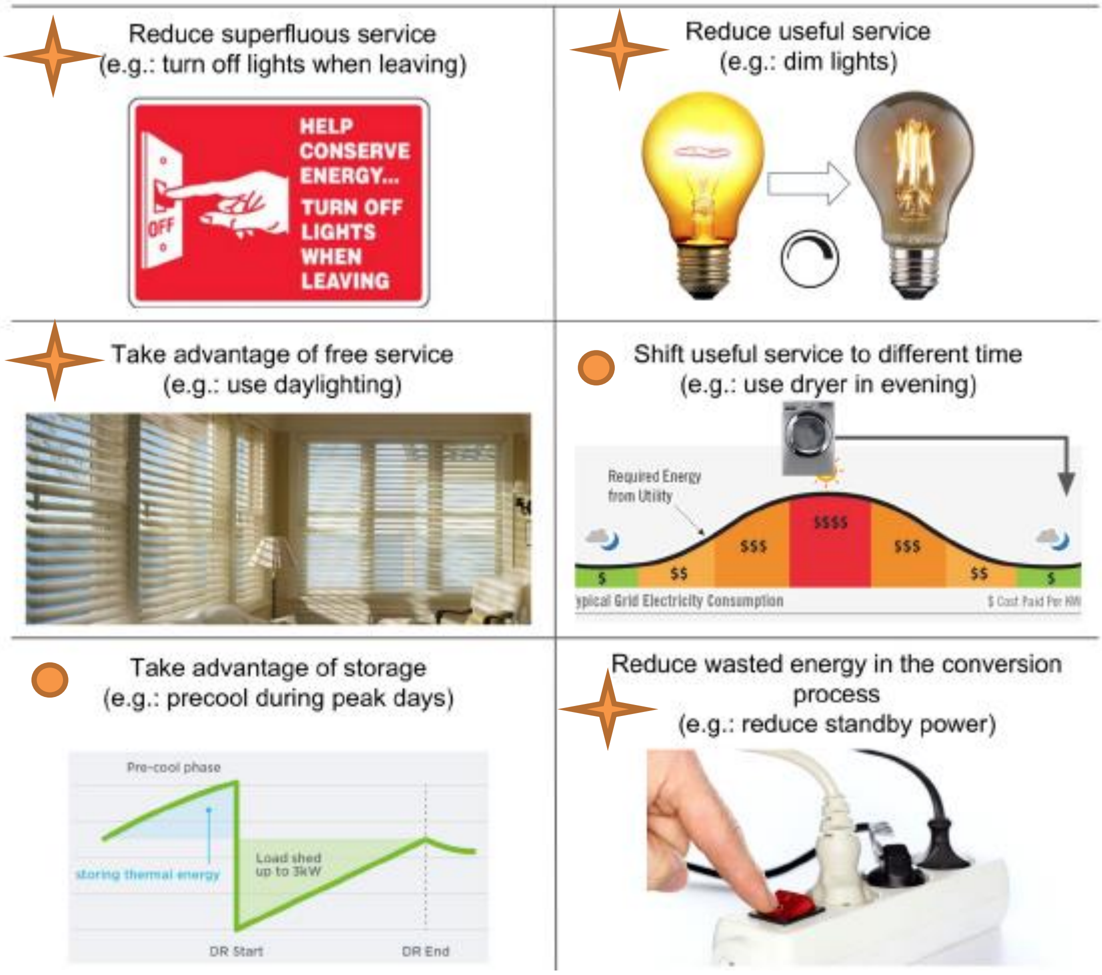
The energy savings determined for each technology are described in the following sections.

3. Residential Sector

Summary of Opportunities

The aim of this research is to examine the potential of Energy Management Systems (EMSs) to reduce emissions, which generally will mean lower energy use, or greater use of renewable energy behind the meter. The strategies that potentially meet this requirement for Home Energy Management Systems (HEMS) are described in a paper at the recent 2018 ACEEE Summer Study on Energy Efficiency in Buildings study (Pritoni *et al.*, 2018). These strategies are shown in Figure 1.

Figure 1: Strategies for Home Energy Management Systems



Source: Pritoni *et al.*, 2018

The HEMS strategies that directly reduce energy consumption are indicated by a star, and are the main strategies behind the energy savings examined for this research. For instance, a smart thermostat will reduce superfluous service by detecting when users are not present and turn off the space conditioning system. For this research we have evaluated the following EMS that are relevant to Victoria:

- Smart thermostats
- Pool pump automation and control
- Lighting automation and control

The two "load shifting" strategies (indicated by a circle in Figure 1) are only able to reduce emissions if the time of use of the shifted energy consumption enables greater renewable energy consumption behind the meter. These load shifting strategies can also reduce energy costs by shifting the energy use into periods of lower prices. The load shifting and energy storage strategies are discussed in more detail in the section: Energy Storage Systems.

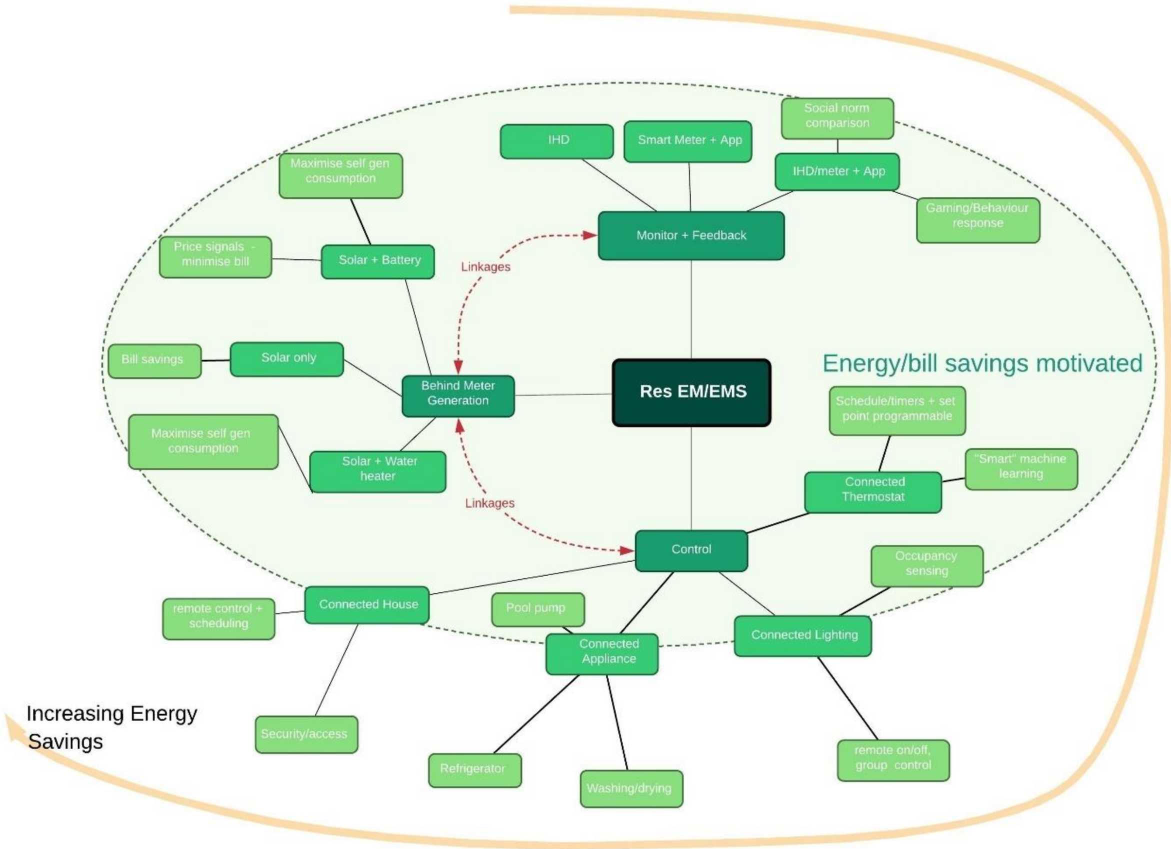
In addition to HEMS that control the energy using equipment, occupant behaviour can also be influenced to reduce energy consumption and hence emissions. These approaches are generally called energy information systems (EIS) or energy feedback reporting. There is considerable research on the different approaches, their key success factors and energy savings potential (Karlin, Ford and Squiers, 2014; Serrenho *et al.*, 2015; Bertoldi and Serrenho, 2016; Gölz, 2017; Nilsson *et al.*, 2018). For the purposes of this research, we have segmented the EIS/energy feedback technology systems into three groups:

- In-home Display (IHD), not connected to another service (App or Web)
- Smart meter and App/Web service
- Meter interface and App/Web service

There is a wide range of energy management systems and energy information reporting technologies/services (some with interrelationships) and various energy savings or emission reduction opportunities. To provide some context to these options, it is helpful to map them into a diagram outlining the opportunities and the possible savings. Figure 2 shows the opportunities, with opportunities that are located within the light green circle indicating where energy/bill savings may drive their uptake. Those outside the circle are more likely to be installed due to their additional features or services, rather than being primarily installed to generate bill savings. For instance, the main motivator for lighting control in the residential sector is user convenience or additional features (like dimming, scene or colour control), however, if connected lighting is linked with occupancy sensors, the controls may reduce energy consumption. Furthermore, the figure shows generally increasing energy/emission savings from the opportunities as we move from energy information to automatic control. The linkages show that opportunities can share similar features, such as energy feedback with connected devices or behind the meter renewable generation/storage.

In summary, the EMS/energy reporting feedback systems and services are evolving rapidly, and their uptake is increasing internationally, with greater levels of data analytics, services and lower costs.

Figure 2: Spectrum of technologies and energy/emission saving opportunities: residential



The products included in the analysis that are assessed as scalable over the period to 2025 are:

- Smart Thermostats
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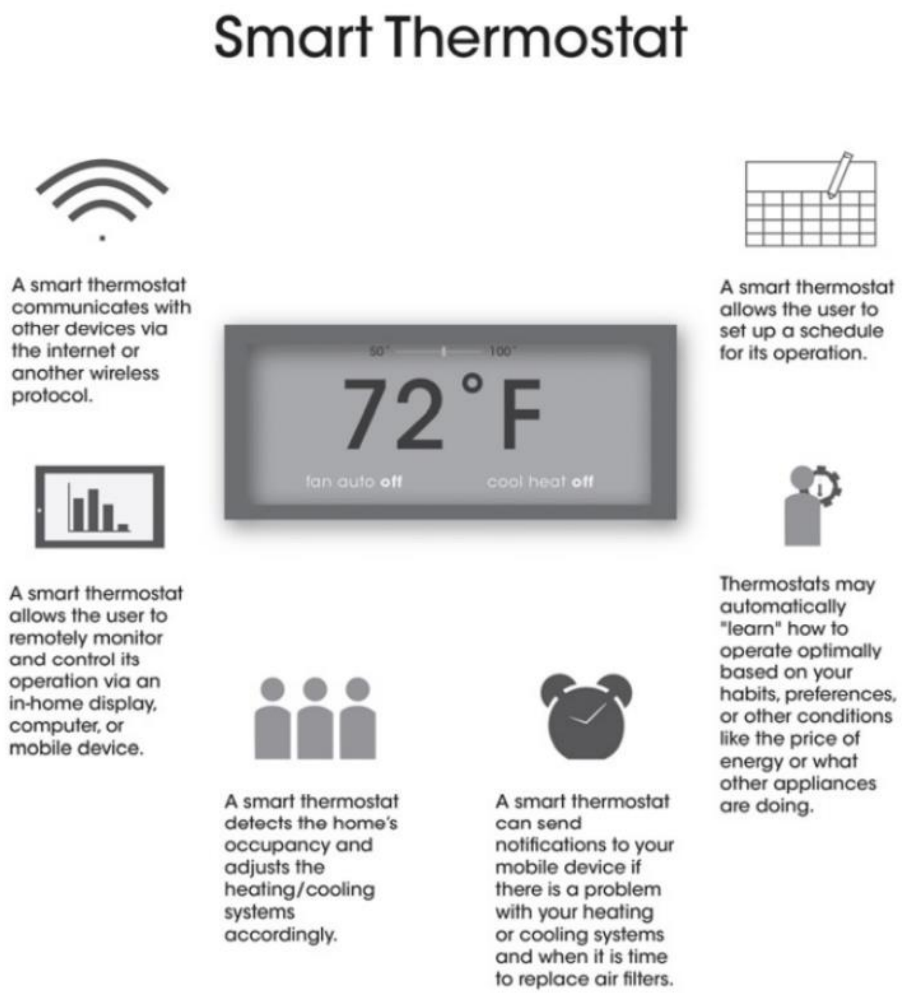
Smart Thermostats

Description

Smart thermostats are a type of programmable thermostat which uses machine learning and external sensor input to make automatic adjustments to space conditioning systems, leading to potential energy savings and improved comfort levels, while reducing the need for active user engagement. Automatic adjustments include creating temperature setbacks[1] which can be activated once a room is deemed vacant and learning the occupant's preferences to efficiently create a comfortable environment. Smart thermostat functions can be grouped into two main types of controllers: the proactive controllers which use prior information on variables like climate and occupancy, and the reactive controllers, which use measurements from a building such as motion sensors (Soudari *et al.*, 2018). They are also called connected thermostats by energy program operators (ENERGY STAR, 2017). A general description of the features of a smart thermostat is shown in Figure 3.

[1] Setbacks are a function of programmable thermostats that adjust the thermostat setpoint to a lower (when heating) or higher setpoint when away or during night time

Figure 3: Smart thermostat functions



Source: (Beth Karlin, Angela Sanguinetti and Rebecca Ford, 2018)

Energy Savings

How do they save

The primary method by which smart thermostats reduce energy consumption is by combining sensor data and machine learning to automatically adjust the heating, ventilation and air conditioning (HVAC) system to be as efficient as possible. They use data such as connected motion sensors, geolocation and pre-existing user preferences to identify the most efficient HVAC cycle, adjusting for weather, occupancy and sleeping hours.

The perceived value of a device such as a smart thermostat is due to the ineffectiveness of programable thermostats, which operate using a basic adjustable timer. In one U.S study, 42% of respondents said they had a programmable thermostat, with 40% of those saying they did not use the programmable features and over 30% disabling or overriding the programmable features (Lomas *et al.*, 2018). These figures show how a thermostat which automatically identifies user preferences would have an advantage over non-smart programable thermostats. The automatic learning and adjusting style of smart thermostats must be effective to have any impact on energy savings while maintaining comfort levels, a US study found that 90% of respondents rarely adjusted their smart thermostat preferences (Li *et al.*, 2019).

One important feature of smart thermostats is automatic temperature setbacks, which activate when the house is vacant or occupants are sleeping, reducing energy consumption. These periods are identified from a range of sensors such as motion sensors, as well as geolocation and learning algorithms (Bryan Urban, Kurt Roth and Chimere Harbor, 2016). Sensing occupancy accurately is essential to adjusting HVAC systems, one method used motion sensors in walkways between zones to identify areas of occupancy. This method further reduced superfluous service, when the occupant is absent and the HVAC is running, leading to 30% reduced energy wastage compared to existing smart thermostat control methods (Soltanaghaei and Whitehouse, 2018).

Estimated Savings

There have been numerous studies on the energy saving potential of smart thermostats, ranging from claims of a 30% reduction in HVAC energy usage to studies finding no significant reduction in energy usage with only a change in comfort levels. This report will base its assumption of a 10% reduction in energy usage, as being equivalent to the reduction in runtime requirements defined by the ENERGY STAR program in the US. In order for a smart thermostat to be included in Energy Star it must pass thorough tests and must prove an annual percent run time reduction of 8% or more in heating and 10% or more in cooling (ENERGY STAR, 2017). Various studies support this claim, for example a review of six studies on smart thermostats energy saving potential for home heating and cooling found that there was an average of 8-15% reduction in energy usage (Sine, 2017).

The energy savings claims can vary with the baseline being used as a comparison. For example, a study compared a smart thermostat to a programable thermostat, instead of baseline HVAC consumption, yet still identified a heating energy saving of 14%. This study further breaks down the savings into 9% being due to reduced heating times and lower set-point temperatures while the other 5% was due to improved operation of the central boilers (Boait and Rylatt, 2010).

There are various claims of greater energy saving potential from smart thermostats, for example a US/UK study found the average heating energy savings were 28% for smart thermostat equipped homes compared to regular household heating patterns (Lomas *et al.*, 2018). Another HVAC control method used a fuzzy logic learning system to minimise user interaction, increasing the effectiveness of smart thermostats learning and adapting processes, leading to HVAC energy savings claims of 21.3% (Keshtkar and Arzanpour, 2017).

However, a number of studies found that real world savings from smart thermostats can be at a reduced percentage. A field study on occupancy responsive smart thermostats in residential university halls found that the saving was less than anticipated. Results found that the smart thermostats reduced energy consumptions by 0-9% and 5-8% for cooling and heating respectively (Pritoni, Woolley and Modera, 2016). A study which centred around reducing run time by switching heating off in the lead up to occupants leaving a house, found saving of between 4-5% of heating energy in UK homes and 4-12% in US homes (Ellis *et al.*, 2012).

Influencing Factors

The effectiveness of energy savings from smart thermostats is dependent on a few factors, related to both thermostat design as well as consumer habits. Variation between studies can be attributed to factors such as the occupancy levels of the residence, the variations in thermostat usability, and how well thermostats predict occupancy.

A study on residential halls at university found that the energy savings during summer, when the majority of students were away, increased to 20-30% for cooling, compared to the 0-9% savings during higher occupancy periods (Pritoni, Woolley and Modera, 2016). Similar links to occupancy and energy savings were identified in variations between homes with regular occupancy patterns compared to homes occupied most of the time, with energy savings from heating varying from 38% to 17% respectively (Lomas *et al.*, 2018). These studies suggest that an increase in both short and long-term occupancy leads to an increase in the energy savings potential a smart thermostat can provide.

The usability of smart thermostats is an important factor in determining the resulting energy savings. A meta-study on heating controls found moderate evidence from usability studies that smart thermostats don't save energy compared to standard thermostats. They cited the difficulty of use of heating controls, in particular with older generations, however they also identified there's minimal large-scale, multi-year field trials on heating controls (Lomas *et al.*, 2018). Further studies have noted the confusion between user input to a smart thermostat and the resulting temperature outputs, making user engagement problematic with more developed AI's such as Nest thermostats (Li *et al.*, 2019). Reduced usability leads to consumers providing less information which can result in increased miss-times and temperature ranges that aren't ideal, all of which can lead to a greater variance in the real-world energy efficiency impacts.

The effectiveness of a smart thermostat is partially determined by how well it can predict occupancy and sleeping, whether a room is 'active' or not and to change temperatures accordingly, with the aim of reducing the overall miss-time. To determine active status, some smart thermostats use occupancy sensors such as motion sensors which, depending on their implementation, can have varying degrees of success. A previously mentioned study found that motion sensors placed in walkways were able to reliably detect occupancy states, however, identified issues relating to sleeping states (Soltanaghaei and Whitehouse, 2018). Other thermostats overcame sensor problems by using combinations of geolocating and deep-learning

AI's to provide accurate predictions of occupancy, however they can encounter problems based from assumptions (Li *et al.*, 2019).

Implementation issues

The VEU program activity design would need to consider serval issues related to the specification and evidence or measurement of energy/emission savings. These include the following:

- Suitable technology for Victorian households. The connected thermostat should be compatible with common heating and cooling equipment, in particular ducted gas heating and air conditioning systems. It is a complex area and only DIY enthusiasts have appeared to installed the common connected thermostats in Australia (Nest do not sell directly to Australia at this time). However, some suppliers (including Zen Ecosystems) have designed systems that are compatible.
- Measurement method. The variation in energy savings from smart thermostats suggests that field measurements may provide suitable evidence to support the level of achievable energy savings. The USA ENERGY STAR program has developed measurement approaches specifically for the connected thermostat (ENERGY STAR, 2017). The specification includes a software tool to standardise the data collection and providing aggregate savings data and associated statistics to EPA every 6 months. The NSW ESS Aggregated Metered Baseline (IPART, 2017) could also provide a methodology for measurement. This methodology is versatile, but relies on energy metering which may increase the measurement burden for natural gas heating products.

The ability to use the data generated by the connected thermostat for measurement of the energy/operating performance of the product can greatly reduce the costs of validating energy savings. However, the establishment of the control group or baseline performance (depending on the measurement approach for the specification) would still require comparable data (such as running times or energy use of the space conditioning equipment). To maintain the Energy Star certification, the US EPA require aggregated savings data to be provided every 6 months for those products installed. Consideration of this type of continuous data provision might enable the generation of VEECs on a similar basis to the Project-Based Activities (PBA) methodology.

There is potential for these products to scale from 2019 to 2025, as

- Energy Star has 11 suppliers and 37 products certified (Dec 2018),
- products have been used since 2011, and
- the European market penetration rate of smart thermostats in 2017 was at 2.5%, which is predicted to increase to 20% by 2022 (ResearchAndMarkets.com, 2018).

Pool Pump Automation

Description

Swimming pool pumps are typically single speed motor/pump used to circulate pool water through a filter. The use of multi speed or variable speed pumps can significantly reduce the energy consumption. The key to obtaining these savings is to automatically control the speed of the pump according to the purpose (filtering the water, backwashing, etc). Many of the variable speed pumps are sold without these automatic controls, relying on the user to manually select the appropriate speed of the pump for the conditions.

A Variable Frequency Drive (VFD), which is an adjustable speed device, can be attached to a single speed pump to control its speed and thereby, improve its energy efficiency. These devices are available in Australia with sophisticated control systems that match the speed of the pump to the required level of filtration and/or chemical dose[2]. The research prepared by EnergyConsult for the *Decision Regulation Impact Statement: Swimming pool pumps* (E3, 2018) determined the average savings of automated variable speed pool pumps compared to a single speed pump was 70%.

Energy Savings

How do they save

The savings from automating pool pumps are derived from the reduced energy use by optimising the pump flow rate to the minimum required to maintain pool water quality. The energy saved can be determined from the Pump Affinity Law, which quantifies that power consumption drops at a nonlinear rate as you reduce the pump speed and water flow, i.e., if the motor speed in halved, the flow rate is also reduced to half, but the power consumption of the pool pump is reduced to 1/8th of the original draw (Hunt and Easley, 2012).

The key strategies for minimising energy use are:

- Reducing the pump speed and flow rate according to measured water quality, including pH, particles, temperature, salts, chlorine
- Predictive control of pump flows based on weather, temperature and observed water quality
- Automatic or time control of pumps, cleaning, chemical treatments

[2] https://www.pooledenergy.com/, https://www.simplybetterpoolsavings.net/ , http://splashmepool.com.au/

Estimated Savings

The energy savings from installing VFD and automatic controls are assessed as 65% of the pool pump energy use. This is based on measured evidence from two Australian reports:

- Sustainability Victoria reported average savings of 50% from a trial of variable speed pump retrofits of 8 sites (compared to existing single speed pumps). These were not automatically controlled, which would increase the level of savings (Sustainability Victoria, 2016).
- Common Capital reported average savings of 50% of all pool pump and ancillary equipment from a trial of 50 sites in NSW. The savings are reduced as the site measurement boundary included energy use that might not be controlled (lighting, chlorinators, pool heating, etc)[3]. The installations were VFDs and pool pump automation (Common Capital, 2016). If the auxiliary equipment is removed from the calculation of energy savings, the savings attributed to the pool pump and VFD are 67%

The study by Common Capital is more appropriate to use as the basis for the estimated energy savings, as it represents the potential for automated pool pump controls and is based on measured data for 50 sites. Further evidence is being obtained by the ARENA trial which started in early 2018[4].

Influencing Factors

As noted, the savings result from both the installation of the VFD and the automatic controls, however if an existing pool pump is already a variable or multi speed pump, the savings would be lower as users may already be manually or timer controlling the pump speed. In general, the savings from automating the control are dependent on the existing equipment and user behaviour. The Sustainability Victoria (SV) study found that retrofits of the 3-speed pumps were operated on their lowest speed setting for most of the time in only three houses. This suggests that automation related savings would be significant as the controls reduce user related variability and energy losses.

Implementation issues

The design of the activity could be suitable to either of a deemed or measured approach within the VEU. Research would be required to carefully evaluate the variability of the energy savings of different equipment/control applications, as there is no standard specifying the control features or performance characteristics. The performance measurement standard for pool pumps is currently being revised and may be useful for defining some aspects of the specification (DR AS 5102.1:2019).

[3] Approx. 75% of the pool system energy use is associated with pool pumps(Sustainability Victoria, 2016)

[4] See https://arena.gov.au/projects/pooled-energy-demonstration-project/

New pool pumps that integrate controls with variable speed pumps could also be considered in the specification of the activity. The major pool pump suppliers are offering automation and control services with their variable speed products. The increase in market share of new variable speed pool pumps will reduce the pool of opportunity for retrofit of single speed pumps with VFD and automation controls over time.

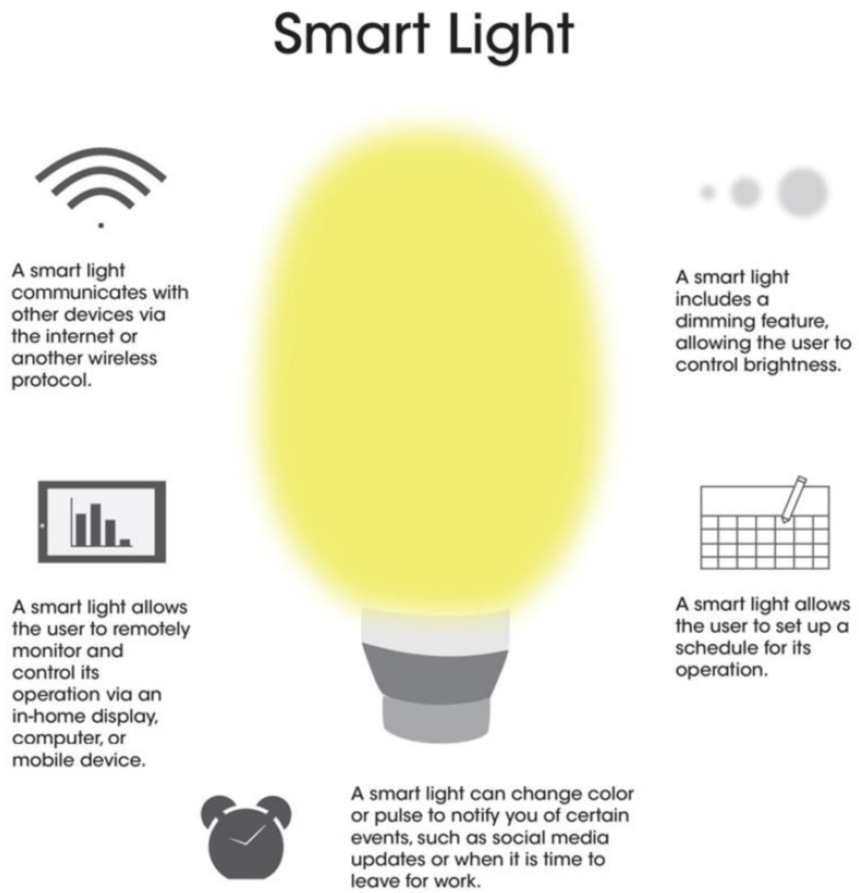
The specification for this potential activity includes the VFD and the connected automatic control system, however there are features that might not relate to energy savings, such as the cost savings from reduced chemical use, improvements in pool water quality and reduced cleaning.

Smart Lighting

Description

There is a wide range of lighting automation and controls, however not all lead to energy savings. “Smart Lighting” and lighting controls in the residential sector are generally not installed specifically for the energy savings opportunities. Rather the main features sort by consumers are convenience, increased control and new features (colour/dimming). The main features of smart lighting are shown in Figure 4

Figure 4: Smart lighting functions



Source: (Beth Karlin, Angela Sanguinetti and Rebecca Ford, 2018)

Energy Savings

How do they save

Lighting can be controlled through smart switches, smart light sources (e.g., bulbs) and smart outlets. These smart lighting services typically offer a remote control, or web/phone app. Some offer occupancy-based control to help reduce superfluous service (at unoccupied times or in unoccupied spaces). Schedules and timers can be useful to reduce superfluous service time, for example by planning the operation of outdoor lights. However, occupancy and light sensors are often preferred to schedulers. Dimming can help reduce superfluous service or to reduce useful service when users want to save energy. When combined with daylight sensors, smart lights can also reduce their output in response to light levels (Pritoni *et al.*, 2018).

Estimated Savings

There is less sources of information, data and studies evaluating the potential energy savings from installing smart lighting in the residential sector, compared to commercial sector. Theoretical estimates based on the amount of time that lighting is used in rooms that are not occupied suggest a technical energy savings potential of 30 to 40%

(Urban, Roth and Harbor, 2016), but do not account for the additional energy use of the network connection that would be required to control the lights. The recent IEA study on Intelligent Efficiency – Smart Homes, estimates smart lighting savings at 10% (IEA, 2018).

As the energy use of smart lighting includes the network connected standby power, which can range from 0.05W to 2.5W, there is some risk that smart lights may actually use more energy annually than an efficient LED light bulb (IEA, 2018), due to the relative size of energy use for maintain the network connection compared to the energy use of the efficient lamp.

Therefore, for the purposes of this research, the 10% savings estimate is used, which may be at the high end of the range of estimated energy saving potential.

Influencing Factors

The quantum of energy savings is likely to be small now that that LED lights are being adopted in Victoria. If the average power use of a LED lamp is 5 to 10W, savings of 10% are relatively small. To obtain savings from superfluous operation requires user input to schedule operation times or occupancy sensors. Most of the products do not have occupancy detection abilities so the realistic savings potential is probably quite low.

Implementation issues

The implementation issues are not addressed due to the low potential for this activity in the VEU. Consideration of the following would be essential:

- Already increasing uptake under BAU with trends indicating multiple suppliers and products
- Relatively low costs for smart lighting products
- Highly uncertain and relatively low absolute energy savings

Energy Feedback Reporting

Description

Energy feedback reporting can be broadly categorized into 2 main types of feedback, indirect and direct feedback. Indirect feedback is provided after consumption occurs in a delayed, one-way format. Examples include standard billing from utilities and enhanced billing, which incorporates energy saving advice and household specific information. Direct feedback is provided in real time, often through the combined use of a smart meter and a connected device. Direct feedback can vary in the complexity of information provided to the consumer, with devices such as In-home-displays (IHDs) providing only premise level information. While more advanced feedback systems can include connected devices, machine learning and diagnostic sensors. These systems can provide disaggregated, device-level feedback, allowing users to target specific energy loads.

In this report we will focus on direct feedback, grouped into three main categories. A basic IHD, an IHD or meter interface with complementary applications allowing for instantaneous feedback, and an app/website in conjunction with a smart meter, providing delayed feedback.

Energy Savings

How do they save

The Alberta Energy Efficiency Alliance (2014) classifies energy feedback reporting as a type of behaviour-based energy saving method. One which aims to increase household's awareness of energy consumption through real-time feedback commonly used in conjunction with goal-setting, comparisons, gamification and education. By showing the household's energy consumption on a device such as an IHD, energy feedback reporting helps raise consumer awareness of their consumption, theoretically leading to a reduction in their energy usage.

The style of energy feedback can vary significantly, however there is a consensus amongst most meta studies of what leads to notable energy efficiency improvements. Most studies found that feedback given in a clear and concise way, using computerised and interactive tools and provided regularly (daily or more), will lead to successful energy savings (Serrenho *et al.*, 2015). Furthermore, improved savings are reported in studies where feedback is more detailed and more closely linked to individual household consumption, such as device disaggregation (Fischer, 2008).

Including supplementary materials beyond a simple IHD also helps improve the effectiveness of behavioural changes. One study found that including extra material that increases interpretation, along with energy saving tips, created a persistent 5% additional reduction in energy usage over an 11-month period (Bird and Legault, 2018). While according to other research it's been noted that IHDs, in conjunction with existing smart metering technology, do not lead to significant energy savings. There's claims that IHDs need to be developed by focusing primarily on user engagement, as the levels of energy savings depend not on the device itself but on how well it can convey to consumers energy saving behaviours (Buchanan, Russo and Anderson, 2015).

Estimated Savings

The degree of variance of what composes direct energy feedback reporting has led to studies reporting energy savings ranging from 2% to 22%. While a degree of this variation could be accounted for, the highly variable nature of study designs there is significant variation due to the nature of the feedback reporting. Disaggregated feedback tends to give more savings than premise-level, while the persistence of the energy saving behaviour is also affected by the way feedback is delivered. In this report, assumptions are based on the more conservative estimates. IHD's alone are estimated to save 6.6% in energy usage[5], while an IHD/meter interface with apps is predicted to save 10%, and the app/website along with a smart meter is predicted to save 4%.

There have been numerous meta-studies analysing the average percent savings in household energy consumption from direct feedback systems. Fredman *et al* (2018) found that real-time feedback led to mean savings of 9%, with studies using just IHDs or a combination of IHDs and incentives both showing to be statistically significant in their energy reduction claims. The Alberta Energy Efficiency Alliance (2014) compared studies which gave disaggregated feedback real-time feedback and studies on premises level feedback, which found the mean energy savings reductions were 13.7% and 8.6% respectively. However, they noted that the costs of installing feedback systems with disaggregated and/or more regular feedback are often much higher, meaning that the potential energy savings of these programs could be outweighed by the associated costs. Ehrhardt-Martinez and Donnelly (2012) also identified the comparison between disaggregated and premise-level feedback, finding a mean annual percentage energy savings of 12% and 9.2% respectively.

Ehrhardt-Martinez and Donnelly (2012) in addition, looked into the levels of persistence of these energy savings. They found that out of 28 long-term studies, 70% of them had energy savings in households which persisted, and of studies that discontinued feedback, 83% of them saw persistent savings. A 2018 study in Sweden found real-time direct feedback systems gave a mean reduction of 9.7% in household energy consumption. This study however, focused on high-income, well-educated individuals wherein the majority reported to have strong environmental motivations to reduce consumption (Nilsson *et al.*, 2018).

A 2017 EU study was conducted on the introduction of IHD's into homes with previously installed smart meters. The study found that IHD's lead to a statistically significant reduction of roughly 5% less electricity consumed than the control. In addition, they found the reduction in electricity remained relatively constant between weekdays, weekends and throughout the day, and that the feedback effects persisted over the course of the 11-month study (Schleich, Faure and Klobasa, 2017).

A summary of studies and types of feedback is shown in Table 2.

[5] This is the current assumption for the VEU

Table 2: Summary of studies and types of feedback

Activity Type	Savings range	Reference
IHD		
	G1 (self monitor a smart meter) by 13%. G21 (real time feedback) 22.2%. G22 (real-time+appliance specific) 23.3%	(Kendel, Lazaric and Maréchal, 2017)
	2.5% (low energy consumption already)	(Khosrowpour *et al.*, 2016)
	7%	(Bird and Legault, 2018)
	2%	(Buchanan, Russo and Anderson, 2015)
	9.2%	(Ehrhardt-Martinez and Donnelly, 2012)
	8.6%	(Alberta Energy Efficiency Alliance, 2014)
Smart meter + App (delayed)		
	9.6-9.7%	(Gölz, 2017)
	5%	(Schleich, Faure and Klobasa, 2017)
IHD/ meter interface + App (instant)		
	9.7%	(Nilsson *et al.*, 2018)
	5-12%	(Fischer, 2008)
	12%	(Ehrhardt-Martinez and Donnelly, 2012)
	13.7%	(Alberta Energy Efficiency Alliance, 2014)
Wide range of feedback reporting activity designs		
Meta study	~6%	(Serrenho *et al.*, 2015)

Influencing Factors

As previously mentioned, there is a high degree of variance in the studies due to how energy feedback can be delivered and how/where the study was conducted. Several aspects of feedback design can influence energy savings, such as the frequency of the feedback and how the interface is designed to maximise user engagement. While the population can also affect levels of energy savings, with factors such as sociological effects, income and pre-existing energy consumption all influencing the savings potential.

One factor that can lead to increased energy reduction levels is the frequency of the feedback. Fischer (2008) concluded that studies which gave feedback on a daily (or more) basis had more significant mean energy savings. Serrenho (2015) also identified higher mean energy savings in studies that gave feedback at higher frequencies, however they were unable to identify any significant difference between daily and continuous feedback. Du (Du, Guo and Wei, 2017) investigated residential electricity demand in China and found that a standalone increase in feedback frequency lead to no significant reduction in household energy consumption.

A number of studies identified another factor that increased the percentage reduction of energy: the various methods of consumer engagement. Fischer's (2008) meta-study of feedback reporting designs found those which "used an interactive element that engages households" all were part of the "best case group" of studies. One type of engagement used gamification tools, such as, comparing similar energy consumers/neighbours or creating a sense of gratification when the consumer's energy performance improves (Serrenho *et al.*, 2015). Consumer engagement can also be increased in conjunction with the frequency of feedback, to provide disaggregated, appliance-specific data and detailed breakdowns of household's energy consumption (Fischer, 2008).

The income level and the size of household energy consumption also influence the degree of savings. Kendel (2017) identifies the high-income and low-income bracket households as having higher potential for large energy savings from energy feedback reporting, while middle income household's energy consumption is less influenced by feedback. In addition, Khosrowpour (2016) found that the change in household energy consumption was influenced significantly by their original energy consumption levels. With both medium and high energy consuming household having no significant change due to feedback, however low energy consumption households had a mean drop of 2.5% compared to the control group. This data suggests that both pe-existing energy consumption and household income can play a significant role in the household's willingness to respond to and engage with feedback reporting. Bird and Legault, (2018) found that persistence of behaviours is influenced by social norm effects such as default temperatures, wherein households more strongly influenced by these effects correlated with an increase in the persistence of the behavioural changes. While the Alberta Energy Efficiency Alliance (2014) also identified external motivation and other social norms as influencing factors.

Implementation issues

The design of a potential activity would need to consider which aspects of feedback reporting would be included and the degree of integration with Victoria's smart meter technology. The current review of the IHD activity will be useful to inform the technology integration issues, especially the costs and processes for installing the compatible IHD. Some IHD/app feedback system suppliers are choosing to not use the smart meter interface due to the integration issues. At least one supplier can monitor multiple circuits and hence provide disaggregated load/energy data, which has been shown in the research to increase the level of savings.

The App/website with smart meter approach needs to be carefully evaluated. Although there is potential for energy savings, the delay in feedback may be too long to consider this method effective. Most Victorian distributors are currently updating energy data from household smart meters 12 to 24 hours later, and then the retailer or other intermediary needs to process and display this data for the user (with some retailers claiming an additional 48 hours is required to display consumption data). However, the consumption information can be provided with less delay, at least 4 times a day and potentially 30 minutes or less according to responses to the Transition to Metering Competition in Victoria – Options Paper (United Energy, 2016). Additionality to the BAU may also need to be considered, as some retailers are already providing feedback apps and website interfaces using the smart meter data, but not specifically evaluating or monitoring the impacts of these platforms.

Energy Storage Systems with EMS

The scope of this study required an assessment of the potential of behind the meter (BTM) control systems (if combined with solar photovoltaic (PV) and energy storage systems or alone) to reduce emissions -either at the site or across the electricity grid.

In order to meet the criteria of emissions reduction, the BTM system must be able to demonstrate either:

- (1) emissions reductions by installing additional renewable energy generation at the site or elsewhere on the grid, than would have been possible without the BTM system, or,
- (2) emission reductions by shifting the timing of loads to periods of lower carbon intensity of grid electricity generation.

Initially, this component of the scope of work was not examined in detail, due to the complexity of the modelling required and the lack of supporting information (such as average ½ hourly electricity usage profile and grid emission factors by time of day/year for Victoria). However, further information was provided and modelling/simulations of typical households undertaken for this 2nd version of the study report.

This is presented in Appendix B: EMS with BTM Strategies. The initial assessment is provided below.

Initial Assessment

1. Emissions reductions by installing additional renewable energy generation

In relation to the first option, control strategies (in conjunction with energy storage systems) that increase the amount of renewable energy self-consumption where there are grid constraints (either local or state wide) may enable greater behind the meter emission reductions. Examples of these situations are:

- Reducing distribution network losses as the energy is used at the site and not exported for use elsewhere in the grid
- Reducing renewable energy curtailment at the regional or system level, where the control strategy shifts demand thereby avoiding curtailment of renewable energy at times of abundant supply.
- Enabling larger installation of renewable energy systems and increased behind the meter energy consumption. This would be the case where network constraints don't allow greater than 6 kW PV systems at the residential premises (or lower kW limits) and where commercial/industrial systems are not permitted to export to the grid. Hence

the larger PV system or proportion of renewable generation that would be additional to the BAU could be attributed to these control/storage systems, and reduce emissions.

Reducing distribution losses by storing energy for use on-site rather than transmitting the energy to other customers would provide very small benefits, as the distribution losses are at most 5 to 10% depending on the distance and connection voltage[6]. The losses associated with the energy transfer of energy storage systems (measured as round-trip efficiency, accounting for battery or heat losses, inverter and battery chargers) are in the order of 10 to 20% (Renewable Energy Agency, 2017; Schimpe *et al.*, 2018). Therefore, from a simple conceptual level, sending energy to the grid will produce lower emissions than storing and using the energy on-site, if only considering the distribution losses

Reducing renewable energy curtailment at the regional or system level in Victoria (and potentially the NEM) requires further information and assumptions about the renewable energy supply capacity and transmission interconnections over the next decade. This aspect of potential emissions reductions is not evaluated in this research.

The remaining example of potential emissions reductions from the use of controls and automated BTM energy storage systems relies on the assumption that additional renewable energy generation can be installed and used, above the BAU situation. For example, households are increasingly limited by distribution network providers to a maximum of 5 kW of exported renewable generation. The site installed PV could be increased to 10 kW, with the additional 5 kW being used BTM for on-site energy use. Similarly, local distribution areas may limit all further exports, where no further grid connected PV is permitted or the household is limited to less than 5 kW. According to *Renew* (formally the Alternative Technology Association), the limit on additional PV installations that are allowed to be grid connected and export is about 30% solar penetration for a distribution region (ATA, 2018).

The key assumption in evaluating the potential for BTM controls and automation (combined with energy storage) is that under the base case, all PV energy generated will be either used on-site or exported, hence displacing grid energy consumption and the emissions based on the carbon intensity of the grid electricity supply. Therefore, the EMS/energy storage systems have to enable more PV to be installed so that energy is able to be either used on-site or exported.

This aspect of the emissions reduction strategy is modelled and the results reported in Appendix B: EMS with BTM Strategies.

It is noted that the *Renew* research suggests that export limit controls with modern inverters may be the more effective at enabling larger PV installations at lower costs,

[6] See https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Loss_Factors_and_Regional_Boundaries/2018/Distribution-Loss-Factors-For-The-2018-2019-Financial-Year.pdf

and with greater benefits to householders. The use of export limit controls is also suggested by a study for the AER (Deloitte Touche Tomatsu, 2018).

2. Emission reductions by shifting the timing of loads

The initial assessment did not explore this option for reducing emissions, as policy assumptions and information on the future carbon intensity by time of day would need to be established. This is a complex area of policy development, and is now investigated in Appendix B: EMS with BTM Strategies in this 2nd version of the report. It relies on the assumption that displacing marginal carbon intensive generation at particular times actually lowers overall emissions. The basis of this theory is that moving loads to the middle of the day (when PV generation maximum) from the night time (when coal generation is dominant) will reduce the higher emission intensity generation required to meet the system load. This might not be the case instantly (due to the longer response times of thermal generation), but might bring forward the retirement of coal generation capacity in the medium to long term. These long term structural changes due to demand response could provide emissions reductions but further investigations are required (McKenna and Darby, 2017).

Voltage Optimisation

Description

Voltage optimisation products are placed at the customer meter box and are designed to regulate the voltage entering the premise to 230V or 220V. Australian utility standards have changed over the last few decades to become uniform with similar country appliance requirements, from the previous requirement of 240V ± 6% to the new standard of 230V+10% to - 6%. Both these ranges allow for a maximum of 253V at the point of supply.

Voltage optimisation products also reduce harmonics and transients that might reduce equipment life. They are also called “Voltage Management Equipment”. There are a number of products on the market, targeting residential and business energy users, and must be installed by a licenced electrical contractor.

The claim of reduced energy consumption in the residential sector is not highly supported.

Energy Savings

The principle theory for determining the energy savings of voltage optimisation products is the application of Conservation Voltage Reduction (CVR), which relies on the electrical formulae of:

$$\text{Power} = \text{Voltage}^2 / \text{Resistance}$$

This means that power consumption for a simple resistive load will increase proportionally with the square of the supply voltage. Hence, the reverse situation is also theoretically valid – where power consumption decreases with decreasing voltage. However, many loads are not simply resistive and are designed to give a fixed output irrespective of the supply voltage. Electrical appliances with thermostatic control or other feedback control loops, will also modulate their operating time to meet the design conditions/thermal loads that are present. It is important to consider the types of electrical loads and how they are impacted by changes in supply voltage. The UK Carbon Trust defines the equipment as:

- Voltage independent, that is their power demand is independent of the supply voltage, within its designed operating range
- Voltage dependant, that is their power demand varies within the designed operating supply voltage range (Carbon Trust UK, 2011)

Other research has classified the behaviour of electrical loads according to the energy consumption, rather than power consumption, as this helps to more appropriately define the impacts of CVR (Ellens, Berry and West, 2012; McKenna and Keane, 2017; Faranda and Hafezi, 2019). The energy consumption is the key performance parameter that is evaluated when considering the potential energy savings. Energy consumption is power x time, typically measured over the period that captures a stable operation state. There are a number of categories is defined in this research, with the simplest classification (Faranda and Hafezi, 2019) described as:

- Loads without feedback: the load-power request is direct function of the supply terminal voltage. For these kinds of loads, when reducing the supply voltage, the load-power request can be reduced and therefore, considering a time period, energy savings can be achieved as well, for example:
  - Incandescent lamps, and fluorescent lamps with an electromechanical ballast, which will reduce their light output and energy consumption with reduced voltage
  - Uncontrolled electrical motors, which reduce their losses when operating at partial loads with lower voltage
- Loads with feedback: usually a control system is adopted to manage the current and power absorption of the device in function of the load working conditions. Therefore, the load-power request is not direct function of the supply terminal voltage. In these loads, the control system manages the load-power absorption usually not producing energy savings as a result of the supply voltage reduction. For example:
  - LED lamps, fluorescent lamps with electronic ballasts
  - Air conditioners, refrigerators with thermostatic controls
  - Kettles, hot water heaters, also with thermostatic feedback controls
  - TVs, consumer electronics and other equipment with electronically regulated power suppliers

The potential energy savings from the installation of voltage management equipment in the residential sector is explored in the following publications:

- IEEE International Conference on Power System Technology (Ellens, Berry and West, 2012)
    - This paper models potential savings in Australia based on the 2007 residential energy use modelling[7] (Energy Efficiency Strategies, 2007), by assuming certain appliances are categorised into similar loads described earlier. The findings were that the savings ratio (% energy reduction/% voltage reduction) was 0.4. The authors note that most of this saving is due to incandescent lighting loads. These lamps will likely to have been replaced by LEDs in Victoria by 2020 to 2025.
- IEEE Transactions on Power Systems (McKenna and Keane, 2017)
    - This paper reports on simulations of CVR strategies in Ireland, with its main focus on differentiating the two categories of loads described above. The finding is that loads without feedback (open-loop loads) provide some evidence of savings at with a savings ratio of approximately 0.5, however other loads do not provide any savings, and can potentially increase energy use (due increased line losses due to power electronic and thermostatically controlled loads increasing their current draw).
- International Journal of Electrical Power & Energy Systems (Faranda and Hafezi, 2019)
    - This most recent paper examines tests results from voltage reduction of a range of residential equipment (LED lights, refrigerators, etc). The results of this study revealed that, in the examined load types, adopting a voltage reduction strategy, even if in some cases an amount of active power reduction can be obtained, the energy saving is always negligible.

The studies examined all support the premise that the opportunity for voltage reduction derived energy savings is reducing as residential equipment changes from uncontrolled loads to controlled loads. The uptake of LED lighting in Victoria (encouraged by the VEU) and the recently announced national MEPS for lighting, suggests that the potential energy savings from voltage reduction will be reduced to close to zero.

The CVR equipment also has losses associated with the voltage regulation. These are in the order of 2% according to VEU new activity submissions[8]. The energy losses are calculated on the entire load of the household, not just the uncontrolled loads, which means that any small energy savings from the uncontrolled loads may not be achieved at all.

[7] This is an older study, that did not predict any take up of LED residential lighting

[8] 98% efficiency: https://www.energy.vic.gov.au/__data/assets/word_doc/0016/75112/Edge-Electrons.docx

4. Business Sector

Summary of Opportunities

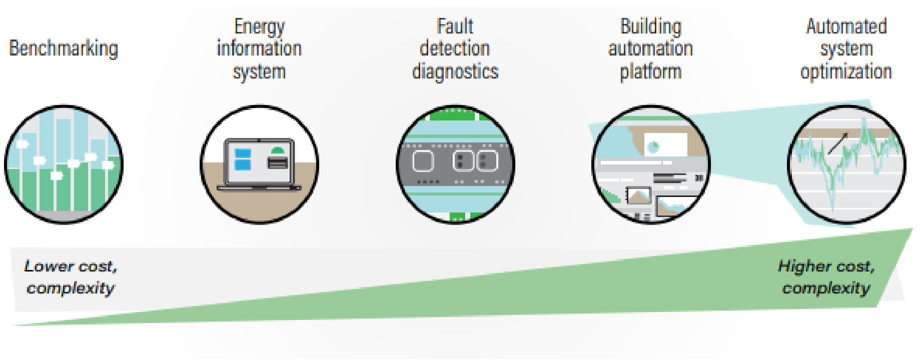
The use of building energy information and intelligent controls is examined within the business sector, largely focusing on the non-industrial segments (offices, retail, hotels, health and refrigerated cold food storage systems in businesses). These opportunities are generally labelled as energy management and information systems (EMIS), but the term is used very broadly and includes a range of opportunities, including:

- Energy information systems,
    - Basic systems such as reporting using smart meter data and analytics
    - Detailed systems measuring individual circuits and particular energy end-uses or equipment (disaggregated data)
    - The above systems with other environmental measurements/data including temperature, humidity, weather forecasts, equipment performance metrics, and integrated analytics/alerts and reporting
- Energy management systems for buildings, typically using energy information systems, but combined with actionable alerts or automatic control of energy using systems (HVAC, lighting), using the building management system (BMS)
- Energy management systems specifically targeting specific end uses and equipment,
    - HVAC - Connected thermostats with cloud based analytics and multi-site controls/systems
    - Refrigeration - optimisation of refrigeration systems using sensors, equipment data and controls, typically with cloud based analytics.

The broad savings potential increases with the degree of disaggregated analytics and automation, as shown in Figure 5.

The IEA have identified that improving the operational efficiency of buildings by using real-time data could lower total building energy consumption between 2017 and 2040 by as much as 10% compared with their Central Scenario, with the majority of this occurring the non-residential building sector(IEA, 2017).

Figure 5: Savings potential and costs of EMIS

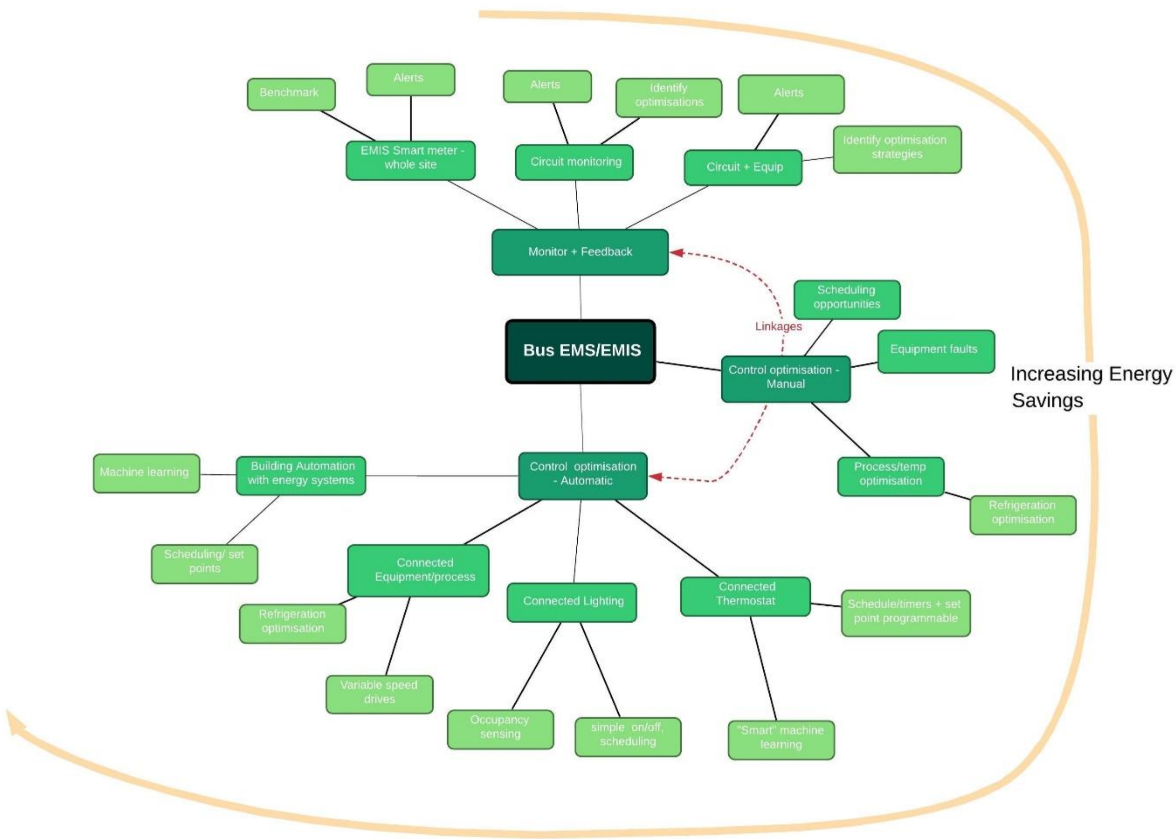


Source: (ACEEE, 2019)

ACEEE conservatively estimates that integrated EMIS with building systems save an average of 8–18% of whole-building energy through the use of smart technologies (ACEEE, 2018) and for poor energy using buildings, up to 50% (King and Perry, 2017).

The range of opportunities increases from simple energy information and feedback, to manual control and optimisation and automatic/intelligent control, as shown in Figure 6.

Figure 6: Spectrum of technologies and energy/emission saving opportunities: business



The products included in the analysis assessed as scalable over the period to 2025 are:

- EMIS – Small – targeting small to medium energy users
    - Basic – typically using premises level energy data from the smart meter
    - Disaggregated – using circuit level energy data from meters installed at the switch board or in the site
- EMIS/EMS – Large. Integrated controls and data analytics targeted larger buildings
- Smart Thermostat/timers – targeting small to medium energy users.
- Refrigeration EMIS: small – targeting just refrigeration systems (cabinets, walk in cool rooms) for small to medium energy users

The estimated savings for each of the products and services is shown in Table 3

Table 3: Summary of estimated savings for business products/services

Product/Service	Estimated Savings	
	Electricity	Natural Gas
EMIS - Small: basic	5%	0%
EMIS – Small: disaggregated	15%	0%
EMIS/EMS - Large	10%	10%
Smart Thermostat/timers	15%	0%
Refrigeration EMIS: small	20%	0%

Energy Management and Information Systems (EMIS)

Description

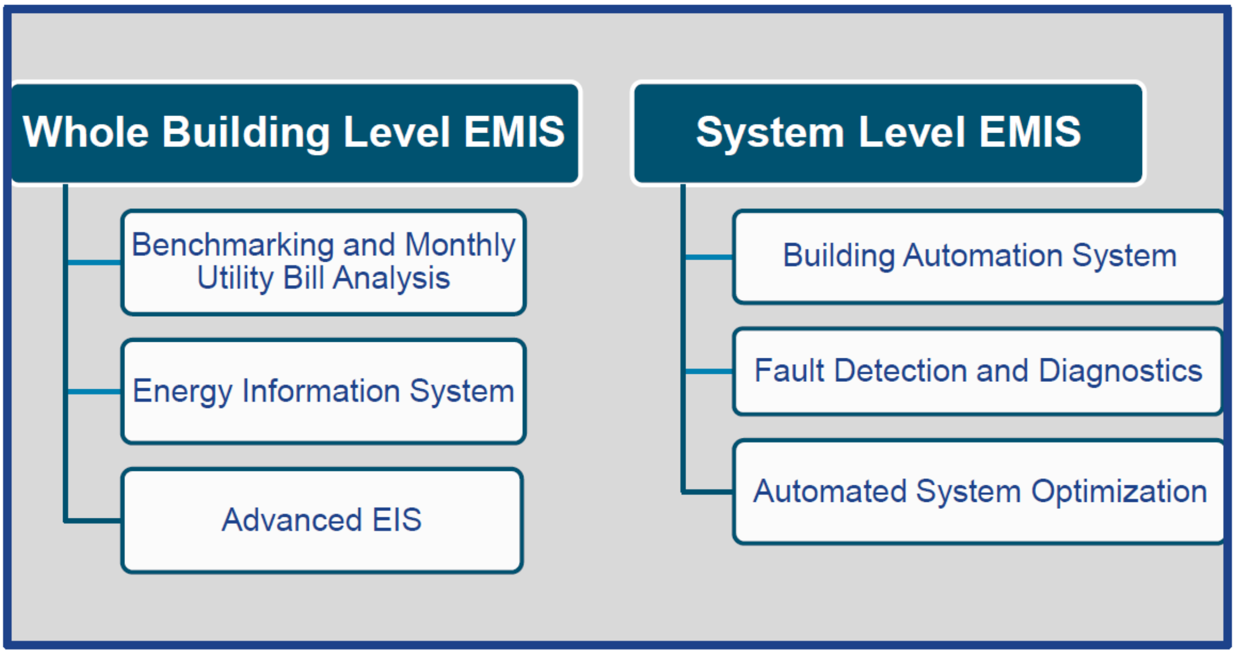
There is a wide range of energy management and information system opportunities, from basic energy monitoring systems at the building level to sophisticated integrated monitoring, data analytics and control systems at controlling the whole building or particular energy using systems (HVAC, refrigeration, lighting etc). They are typically made up of software and hardware systems (sensors, meters, and computers). The software is often provided through a software-as-a-service (SaaS) agreement, but can also be standalone platforms. These systems, which allow users to view the performance of their facilities online, are commercially available from such companies as ABB, Emerson, Siemens, and Schneider Electric (Rogers, Whitlock and Rohrer, 2019). There are also tens to hundreds of smaller service providers who are specialising in EMIS or EMIS as part of their fault detection/maintenance provision or facility management/security services. For this research, the suitable EMIS for a particular site is defined according to the amount of the energy use, small (to medium) and large. Small to medium sites are generally SMEs (retail, offices, hotels) that consume up to

200 MWh pa, while larger businesses are above this threshold. SMEs generally have limited or no building management systems (BMS), usually relying on the controls available in the end-use equipment. In larger sites, a BMS might be present or if not, the energy use (and potential savings) can justify the costs for installing an EMIS with the BMS or integrated EMIS over the top of existing equipment controls (ACEEE, 2018).

A range of functions is provided by an EMIS (as shown in Figure 7), including:

- Benchmarking and bill comparisons
- Disaggregated energy use by end-use and optimisations
- Integrating with BMS and optimisation of equipment
- Fault detection and diagnostics (FDD) and automatic system optimisation (ASO)

Figure 7: Functionality of EMIS



Source: (Granderson, Lin and Hult, 2013)

The range of energy savings is similarly broad, with estimates ranging 2.5% to 30% (Granderson, Lin and Hult, 2013), to 50% (King and Perry, 2017).

Energy Savings

How do they save

The savings from EMIS are derived from a range of strategies, including:

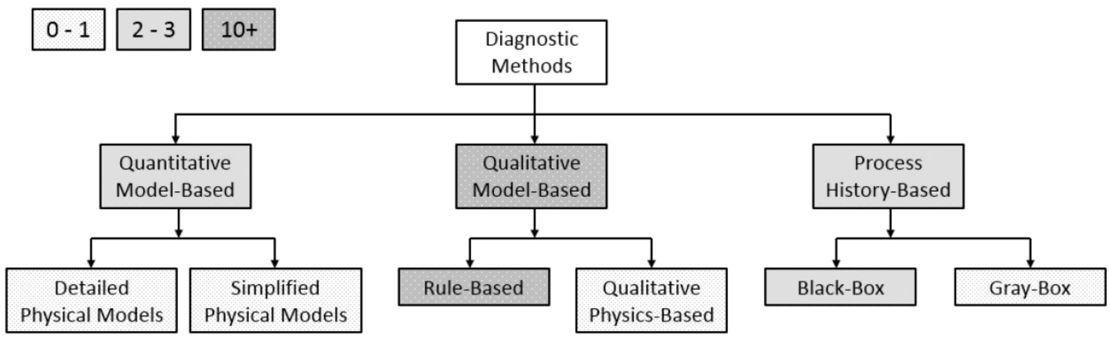
- Identifying poor energy performance by comparing energy use to similar facilities (i.e., benchmarking to a sector or to a portfolio of buildings) or continuous comparing energy use to similar historical period
- FDD and energy anomaly detection

- Energy performance optimisations of HVAC, refrigeration and lighting systems (some aspects are called continuous or monitoring-based commissioning)
- Predictive control and optimisations based on building environment, building loads, weather and other variables (occupancy, historical performance, etc)

Some of these strategies require user input to facilitate the energy savings strategy (such as alerts sent to maintenance staff/contractors, or manually resetting overrides), while others can be completely automated (such as HVAC system scheduling, increasing outside air in response to monitored CO_2).

Most of the EMIS tools integrate FDD as a key feature of their platform. A range of methods are used for detecting faults and anomalies, ranging from quantitative and qualitative models to historical based comparisons. Figure 8 shows the results of a recent survey by LBNL of the approaches by suppliers of tools in the USA (Granderson *et al.*, 2018). The model-based methods rely upon knowledge of the underlying physical processes and governing first principles. The process history-based (data-driven) approaches do not rely upon knowledge of first principles, but may leverage some degree of engineering knowledge; they rely upon data from the system in operation.

Figure 8: FDD and energy anomaly detection methods



Source: (Granderson *et al.*, 2018)

The degree of savings potential is large, particularly when energy using systems are not maintained or regularly serviced. There are often non-energy benefits that can be attributed to EMIS, including reduced unscheduled maintenance and increased productivity due to early fault identification. These benefits can be larger than the energy saving benefits, and are sometimes a key selling point for some types of EMIS providers.

The research for this study has grouped the types of EMIS systems as follows:

- EMIS – Small: Basic. Largely using the existing smart meter data, or possibly a separate connected interface (smart meter or CT) to display and assess the energy use of the site. Providing simple benchmarking with similar sites, historical comparisons and identification of obvious anomalies. Information would be provided by web/app and regular reports to the user.

- EMIS – Small: Disaggregated. Building on the basic EMIS, these systems include additional metering at the circuit or major equipment level, performing limited fault detection (based on rules or machine learning), they can be used for system re-commissioning and testing optimisations. Continuous, fine level (time) monitoring enables greater reporting and interrogation of outlier observations (Granderson and Lin, 2016). These systems can be potentially integrated with other site data to identify energy saving opportunities or performance optimisations
- EMS/EMIS – Large. These are complete systems that typically include all the above, and enable automatic or predictive control, as they are integrated into the building management system.

These categories capture the range of systems and functions currently in the market, as described in the recent ACEEE report (Rogers, Whitlock and Rohrer, 2019). They are segmented to different sized facilities in this report to enable the calculation of the of overall impact by segment.

Estimated Savings

The estimated energy savings potential from installing EMIS within the three groups are sourced from a wide range of literature, interviews with suppliers/consultants and supported by observations by this study team members.

The energy saving estimates used in the study for each of the three categories of EMIS are shown in Table 4, with the range of estimates and sources provided.

Table 4: EMIS energy savings estimates and sources

EMIS Type	Savings Estimate	Source
EMIS – Small: Basic (5%)		
	2.4%	(Granderson, Lin and Hult, 2013) benchmarking only
	5%	(New Buildings Institute, 2009)
	5%	(Granderson and Lin, 2016) for basic
	5 – 30%	Observations by consulting team from audits/services
EMIS – Small: Disaggregated (15%)		
	5-10%	(ACEEE, 2019) for cloud-based
	8%	(Granderson, Lin and Hult, 2013) median savings
	16%	(National Science and Technology Council, 2011)
	15%	Savings identified from sub-metering by consulting team from audits/services
EMIS – Large (10%)		
	30%	(IEA EDNA, 2017a)
	17%	(Granderson and Lin, 2016) for enterprise large EMIS
	16%	(Lee and Cheng, 2016) in Taiwan
	8 – 18%	(ACEEE, 2018)
	Up to 50%	(King and Perry, 2017)
	15 - 20%	(CRC for Low Carbon Living, 2018)
	5-25%	(Energy Trust of Oregon, 2017) for FDD
	20 - 26%	(Waide *et al.*, 2013) 26% for hospital. Average of 20% for all EU business buildings sector
	10-30%	(CSIRO, 2015)
	5%	(Nguyen, 2018) for hospital
	15%	(BuildingIQ, 2018) for HVAC in a 5-star NABERS office

Influencing Factors

There is a wide range of energy saving estimates for these types of EMIS, partly due to the sources using multiple evaluation methods, but most significantly due to the nature of the EMIS and the characteristics of the building. Generally, the older and poorly maintained buildings provide the greatest energy saving potential, however even a high performance (5 star NABERS) building was able to achieve a 15% efficiency improvement of the HVAC system from the installation and use of a sophisticated EMIS (BuildingIQ, 2018). The key influencing factors distilled from the literature are:

- Basic EMIS can increase awareness of energy costs and identify poor performance, which is not usually top-of-mind for SMEs
- There is a wide range of systems available with vastly differing functionality, suitable for small, medium and large energy users. This will influence the degree of savings opportunities, with a related dependency on how much user interaction is required to achieve the savings

Finally, FDD provides significant non-energy benefits, which affects the overall perceived and real benefits that can be achieved. In some cases, the reduced maintenance costs might pay for the ongoing system fees.

Implementation issues

The design of the activity could be suitable to either of a deemed or measured approach within the VEU. The data analytics that are inherently available from EMIS, to measure the energy saving performance and potentially baselines, provide several options for activity design. The EMIS – Small: basic category could be investigated as a deemed measure, with a minimum level of performance specified, and reporting aggregated results on a regular basis (and VEECs awarded on a continuous basis). In the USA, utilities are seeking to implement programs that include "pay-for-performance" type measurement approaches (Metoyer *et al.*, 2018), or integrate energy data into measurement of programs, such as the Open Energy Efficiency project(OpenEE, 2019).

The methodology for measuring savings under the PBA is probably highly suitable for large EMIS installations. Consideration could be given to simplifying/standardising the measurement approach to enable a less burdensome requirement, as the whole site energy data and potentially specific end use data might allow greater level of measurement accuracy.

Consideration would need to be given to the attribution of savings to the EMIS vs other energy saving activities that might be undertaken on the site. As an equipment upgrade undertaken separately (or possibly identified due to the EMIS) might be included in the energy savings.

Smart Thermostat/Timers

Description

This measure is similar to the residential sector opportunity, however the advantage for businesses of the management of multiple connected thermostats (either on the site or a portfolio of sites) is an additional feature (Rovito, Subramony and Duffy, 2014). Also, the occupancy sensing machine learning aspect of the smart thermostat is sometimes not a desired feature for business applications. For instance, the business may want to control multiple site AC equipment temperature set-backs, operation schedules and over-rides, rather than allow an algorithm to determine the operation.

The key features for business-based smart/connected thermostats are:

- Multiple site control/grouping
- Scheduling policy, temperature control and override control
- Remote monitoring and control
- Occupancy sensing (if required)
- System wide energy or run time reporting
- Potential predictive control based on weather or other factors

Energy Savings

How do they save

The energy savings from this opportunity are derived from:

- Reduced operating run time and occupant/user changes of temperature set points (reduced superfluous service)
- Site wide control of temperature and reducing system operation outside of operating hours
- Reduced operating time or temperatures when un-occupied
- Predictive cooling/heating based on weather and historical performance to minimise overall energy use.

In addition, the connected thermostat can also enable participation in demand response programs.

Estimated Savings

This study estimates that smart thermostats will save 15% of HVAC energy use. The basis for this is:

- 10% of HVAC for retail buildings, 5 to 30% for office, 10 to 30% of guest room HVAC for hotels (ACEEE, 2017)
- 20 to 30% of HVAC (Zen Ecosystems, 2019)

Influencing Factors

The key factors identified by ACEEE, in the study on smart buildings (ACEEE, 2017), were:

- Smart technology involving human interaction does not automatically generate the kind of energy savings that we immediately see when replacing an incandescent lamp with an LED,
- There is a wide variation in energy savings due to the business segment (office, retail, hotel) and type of features that are suitable (learning vs scheduling).
- Non energy benefits are potentially a key aspect driving the installation and use (such as greater control over comfort and conditions for business customers/staff).
- Suitability and compatibility of the "smart" technology with the existing HVAC equipment.

Implementation issues

There is potential for this activity to be undertaken within the deemed or measured approach in the VEU. Further investigations will be required to determine the appropriate framework, however the availability of data (equipment run time and energy use) relating to the operation of the controlled HVAC equipment may enable simpler measurement approaches (similar to the Energy Star methodology for connected thermostats (ENERGY STAR, 2017)).

The pricing and business models of the suppliers can also influence the implementation approach. If the supplier uses an ongoing fee for provision of the software platform, this could be offset by VEECs generated depending on the achieved/measured performance

Refrigeration Optimisation

Description

Refrigeration optimisation and FDD using digital measurement/control technologies is a form of EMIS specifically targeting an energy end-use system. The principle aim is to ensure the refrigeration system performs optimally (keeping the products at the required temperature/humidity) while minimising energy use. The features of these types of systems are:

- Monitoring of various key performance characteristics, i.e., temperatures, humidity, refrigerant line pressures, door openings, equipment energy use/run time
- Real time diagnostics to identify malfunctions and performance vs boundaries of expected operation
- Cloud-based remote monitoring, control and alerts for single or multiple sites
- Expert/intelligent systems to diagnose issues and optimise the system.

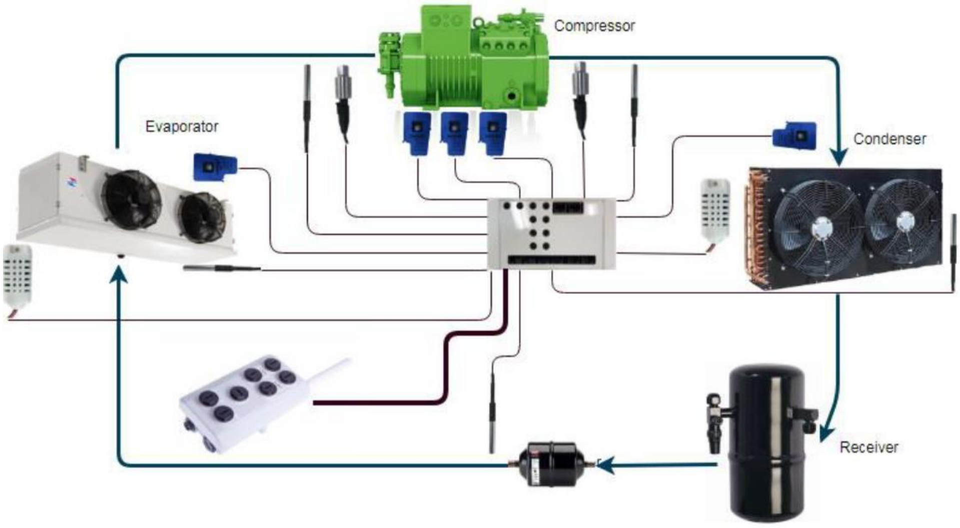
The use of these types of refrigeration monitoring systems often enables the remote diagnosis and continuous optimisations that on-site technicians usually perform, reducing the need for service calls, unexpected faults and energy use. An example of the hardware used for such a system is shown in Figure 9.

Some manufacturers of these types of equipment only include cloud-based monitoring and alerts, with the technical service/maintenance contractor (or staff) required to rectify the performance issue remotely or on-site[9].

The target market for this type of EMIS are refrigeration systems with remote condensing units, which are commonly found in supermarkets, food service facilities and the cold food retail segment. These remote condensing units typically service refrigerated display/storage cases and walk-in cool rooms, and are described in *Cold Hard Facts 3* (Expert Group, 2018).

[9] For example, the Frigbot, see https://frigbot.com/en/

Figure 9: Hardware for refrigeration monitoring and optimisation system



Source: (Metis Monitoring, 2018)

There are several suppliers of refrigeration FDD and optimisation EMIS, with the scope of their products targeting only refrigeration systems or are sold as part of a wider EMIS. The LBNL survey found that 10 EMIS (out of 14) included commercial refrigeration systems within the scope of the product (Granderson *et al.*, 2017).

Energy Savings

How do they save

There is a range of savings opportunities from a system EMIS, with many of the opportunities similar to those described in the earlier section (Energy Management and Information Systems (EMIS)). The energy saving strategies include:

- FDD and energy anomaly detection, specifically designed to detect refrigeration system faults.
- Benchmarking performance with comparisons of current energy use against past performance or expected performance
- Refrigeration system optimisations to reduce over use of defrost cycles, unusual refrigerant pressures, correct temperature/humidity settings, reduce door openings, etc
- Predictive control and optimisation-based machine learning

Estimated Savings

The energy savings estimated for the refrigeration optimisation is 20% of refrigeration energy use, based on a range of studies, including:

- 18% for commercial refrigeration EMIS (Granderson and Lin, 2016)
- 15- 30% for commercial refrigeration EMIS (ACEEE, 2017)
- 20 -50% for cloud based optimisation system (Graziano and Pritoni, 2014)

- 10 to 45% from the AIRAH/SV study (ARA, 2019), with an average of 10% savings for all the sites, achieved by a service/fault repair and recommissioning[10].

A supplier interviewed for this research (Metis Monitoring) claims that most of their customer sites have achieved 30% savings of refrigeration energy use from installing their system. However, this energy saving value would represent a segment of the market that actually implemented actions identified by the refrigeration EMIS.

The 20% estimated energy saving is potentially at the higher end of the average achievable energy savings for this activity, however the VEU activity design could utilise the data from the EMIS system for verification and compliance, which would reduce the implementation risks.

Influencing Factors

As previously noted for EMIS, there is a high degree of variation in the potential savings depending on the system installed and the performance of the underlying refrigeration system. Although refrigeration system optimisation controls and EMIS are not as developed as HVAC systems, there are similar process for identifying and rectifying faults and anomalies (Behfar, Yuill and Yu, 2017).

Several aspects of FDD and optimisation strategies can influence energy savings, such as the scope of monitored equipment and parameters, reporting mechanism (alerts, faults), maintenance/rectification actions undertaken and type of expert system used (qualitative, quantitative, process history).

Implementation Issues

This type of activity may be suitable for a measurement approach under the VEU, due to the high number of dependent factors affecting the potential energy/emission savings. Similar to the EMIS activity, data are inherently available from refrigeration EMIS/optimisation systems, as they use extensive data analytics to measure the energy performance and system parameters. These could be used to provide activity results and potentially baselines to measure the savings achieved.

However, the ARA study conducted for SV (ARA, 2019) found that the largest barrier to achieving the savings identified by the EMIS is getting the owners/operators of the refrigeration equipment to implement the energy saving strategies. This barrier may be addressed by careful VEU activity design, including linking the certificate creation to achieved emissions reductions.

A second significant barrier is that installing EMIS system beyond fault detection/recommissioning may require some of the refrigeration system components

[10] Summary information from paper presented at conference, ATMOsphere Australia 2019, see http://www.atmo.org/events.programme.php?eventid=77. Paper found at https://www.slideshare.net/EdaIsaksson/michael-bellstedt-minus-40-on-behalf-of-sustainability-vic

to be upgraded to make use of all the optimisation and improvements that the EMIS diagnostics can provide.

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Appendix A: EMS Uptake and Impact Assessment

Overview of Impact Assessment Methodology

The methodology to estimate the impact of EMS systems on energy use and emissions, and calculations of potential VEECs over the period to 2025 is described below:

- Estimate the total market size in terms of commercial floorspace or residential households
- Estimate the segment energy consumption by fuel
- Estimate the end-use share for each segment
- Calculate the addressable energy that will be impacted by the technology or service
- Under BAU conditions
  - Estimate the take-up rate of the technology or service, using an S-curve function
  - Apply the percentage savings from the sourced evidence or assumptions
- Under the VEU
  - Estimate the take-up rate of the technology or service, using an S-curve function to find the max annual take-up
  - Using a take-up function based on the % of costs subsidised by the VEECs or payback after VEECs, calculate the VEU take-up (up to the max annual take-up)
  - Apply the percentage savings from the sourced evidence or assumptions

Key inputs and assumptions

The key inputs and assumptions are provided below:

Common Inputs

The sources for market size, energy use intensity, numbers of buildings and estimated technology penetration (by 2030) are shown in Table 5 and Table 6

Table 5: Residential sector common inputs

Input	Source or Value	Notes
Victoria Market Size 2020 -2030		
Residential Households	RBS (EnergyConsult, 2015)	Based on ABS, Can be updated if required, the analysis is not that sensitive to changes in households
Energy Use Intensity	RBS (EnergyConsult, 2015)	Generally decreasing trend
End use shares	RBS (EnergyConsult, 2015)	
Unit Energy Consumption	RBS (EnergyConsult, 2015)	Stock average energy consumption per appliance
Ownership	RBS (EnergyConsult, 2015)	Used to calculate the number of appliances and equipment
Technology take up (BAU)	**Max penetration in 2030**	S-curve function used to model penetration with variables for year and %
Smart Thermostat NG	10% (EnergyConsult, 2019)	Estimated based on current trends and costs to retrofit
Smart Thermostat AC Duct	49% (EnergyConsult, 2019)	Increasing suppliers with models including the product
Smart Thermostat AC Split	22% (EnergyConsult, 2019)	Increasing suppliers with models including the product
Lighting	52% (EnergyConsult, 2019)	Several suppliers including low cost connectivity for lighting
Pool Pump Automation	8% (E3, 2018)	Costs are high and do not support rapid uptake
IHD	2%	Current VEU activity is only approx. 4,000 per year
App + Smart meter	50% (Estimate)	May be easily integrated by retailers
App + Meter Interface	10% (Estimate)	Solar and other BTM installations are encouraging activity

Table 6: Business sector common inputs

Input	Source or Value	Notes
Victoria Market Size 2020 -2030		
Commercial sector	CBBS (Pitt&Sherry, 2012)	Trends from 2010 to 2020 used to extend forecast to 2030
Energy Use Intensity	CBBS (Pitt&Sherry, 2012)	For each segment, offices, retail, etc
End use shares	CBBS (Pitt&Sherry, 2012) Retail segment (ClimateWorks Australia, 2011)	For each segment, offices, retail, etc
Buildings	CBBS (Pitt&Sherry, 2012) SME and retail (KPMG, 2017) ABS 816503	For each segment, offices, retail, etc
Technology take up (BAU)	**Max penetration in 2030**	S-curve function used to model penetration with variables for year and %
EMIS - Small: basic	25% (Estimate)	Estimated based on current trends and costs to retrofit
EMIS - Small: disaggregated	25% (Estimate)	Estimated based on current trends and costs to retrofit
Smart Thermostat/timers	25% (Estimate)	Estimated based on current trends and costs to retrofit
Refrigeration EMIS: small	10% (Estimate)	Estimated based on current trends and costs to retrofit
EMIS/EMS - Large	60% (Estimate)	Trends are for greater take up due to digitisation of building management systems

Costs of activities

Costs for each of the potential options are derived from the research, as shown in Table 7. The costs were reduced in future years at a rate of 5% pa to account for increased scale of production and learning.

Table 7: Estimated costs of activities

Activity	Estimated Costs	Source/Notes
Residential		
Smart Thermostat NG	$160 per product	Average based on Nest, EcoBee, etc
Smart Thermostat AC Duct	$250 per product	Estimated from interviews with suppliers, more difficult to obtain compatibility with a range of AC products
Smart Thermostat AC Split	$60 per product	Estimated from suppliers of AC products, becoming more common on split AC
Lighting	$100, for up to 3 - 4 lights	USA sources and products available in Australia
Pool Pump Automation	$500 per product	Including the VFD
IHD	$70 per site	Average IHD
App + Meter Interface	$150 per site	Interviews with suppliers, but not including ongoing fees
App + Smart meter	$5 per site	Estimated, software costs for a large customer base
Commercial/Business		
EMIS - Small: basic	$100 + $120 annual	Interviews
EMIS - Small: disaggregated	$3,000 + $720 annual	Interviews
Smart Thermostat/timers	$500 + $90 annual	Interviews
Refrigeration EMIS: small	$1,500 + $120 annual	Interviews
EMIS/EMS - Large	$28,000 + $2,000 annual	Based on the high-range costs from ACEEE (ACEEE, 2017) and interviews

Appendix B: EMS with BTM Strategies

Introduction

Further to the analysis conducted for the VEU in the first half of 2019, DELWP commissioned a more detailed examination of the potential opportunities from combining behind the meter (BTM) controls with solar PV to determine the potential of several strategies (single or combined) to create emission reductions in Victoria over the period 2020 – 2025. This appendix reports the analysis and results of this further examination.

Additional information was provided by DELWP projecting the carbon emissions intensity profile of grid electricity till 2040, by hour of day and within each quarter of the year. Also, a detailed model of the energy flows of a typical household was constructed to analyse various BTM strategies when combined with solar PV and the impact on the time of electricity use and export by day within 30 min intervals for a year.

In order to meet the criteria of emissions reduction, the BTM system must be able to demonstrate either:

1. emissions reductions by installing additional renewable energy generation at the site or elsewhere on the grid, than would have been possible without the BTM system[11], or,
2. emission reductions by shifting the timing of loads to periods of lower carbon intensity of grid electricity generation.

The options are examined for the residential sector only and are summarised as follows:

- Battery Energy Storage Systems (BESS) and control strategies, which enable the timing of BESS charging and discharging, and increase BTM consumption and reduce grid emissions
- Electric storage hot water system (HWS), diverter and control strategies, which enable the timing of the diverter to maximise solar PV BTM consumption and reduce grid emissions
- Electric Vehicle Supply Equipment (EVSE) that controls the timing of EV charging when PV is available and reduce the grid emissions
- Control of Air Conditioner (AC) systems to potentially pre-cool the building when PV is available and reduce the grid emissions

[11] This can also be referred to as enabling additional PV hosting capacity of the grid (either local or regional)

All these strategies can also be used together or individually to increase the hosting capacity of the grid (local or regional), thereby proportionally increasing the PV that can be installed. In most situations, it would also be optimal that the control of BTM PV loads be staggered so that additional PV hosting is realised, as each strategy alone is able to offset only part of the PV generation (depending on the size of the PV).

The analysis approached used for these EMS BTM strategies differs from the approach used in the first part of this report. As they are not likely to save energy, the approach of calculating of emission reductions due energy savings is not appropriate. The estimated emissions reduction is determined by:

- Calculating the emissions reduced by enabling greater amounts of solar PV to be installed – this is the emissions reduced by using solar instead of the higher emissions intensity grid delivered electricity
- Calculating the annual emissions from normal operation of the equipment/appliances/PV generation and the emissions from the controlled option. Then using the difference to estimate the emissions reduction over the lifetime.

Having the hourly emissions intensity profile for the Victorian electricity grid enables these calculations, and therefore the strategies described below show the results of these calculations in terms of emissions reductions rather than energy savings potential. More details on the modelling are provided in Energy Flow Simulation Model.

Battery Energy Storage Systems and Control Strategies

Description

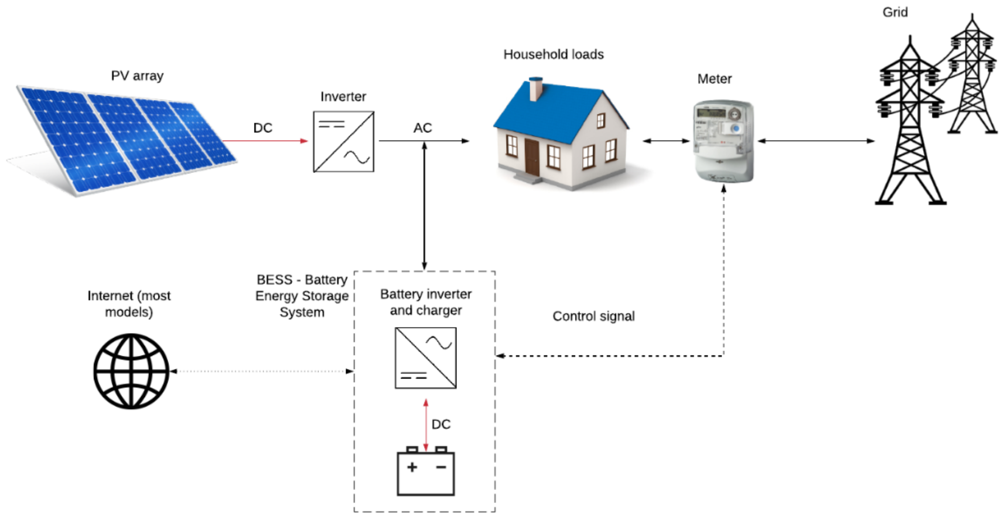
BESS can be used to store excess energy from rooftop solar PV and discharge the energy when required, such as when household consumption increases and grid electricity is being imported. A BESS can supply the entire household energy if there is sufficient solar PV generation and BESS capacity. The BESS requires a level of control to be able to perform these functions, typically by monitoring the energy exported/imported, the level of charge and in some cases responding to external signals due to demand response (DR) events. These features can be implemented by the combination of a Battery Management System (BMS), Home Energy Management Systems (HEMS) and/or inverter/battery controls. The features of these types of systems can include:

- Monitoring of various key performance characteristics, i.e., energy flows to/from the grid, PV generation, voltage, battery system State of Charge (SoC), weather conditions/solar resource available or forecast
- Real time control of the battery charge and discharge operation
- Cloud-based information displays, control and alerts based on pre-determined conditions or external DR events, or energy prices.

An example of the hardware used for such a system is shown in Figure 10. There can be other configurations, including PV DC being supplied to a hybrid inverter/charger, modular BESS/batteries, or combinations of these elements. The BESS monitors the grid supplied electricity to determine when to start charging the battery and discharging.

Some manufacturers of these BESS include cloud-based monitoring and alerts, while others can use third party providers of these cloud services. Almost all BESS have a cloud-based monitoring system.

Figure 10: Basic elements of a battery energy storage system



There are over 18 suppliers and 100 BESS or battery systems on the Clean Energy Council's list of currently approved batteries[12]. The activity modelled for this opportunity involves adding controls and automation to an existing BESS/PV or new BESS/PV that are capable to control the timing of charging for a fleet of systems. Several suppliers would already have the capacity to undertake this type of control using existing hardware, while others may require changes to their hardware and software.

In addition, the strategy has been modelled to only "delay" the timing of BESS charge depending on the forecast of day ahead solar resources and household energy consumption, and state of charge. If the required BESS energy to fully charge is less than 60% of the day ahead solar available forecast energy, the charging can be delayed. This is a simplified algorithm designed to ensure that sufficient excess solar will be able to meet the BESS required charge with part of the available solar, given the uncertainties of forecasting both available excess solar and energy usage. More sophisticated and complex algorithms or machine learning would actually be implemented in practice.

[12] https://www.cleanenergycouncil.org.au/industry/products/batteries/approved-batteries as off 19 September 2019

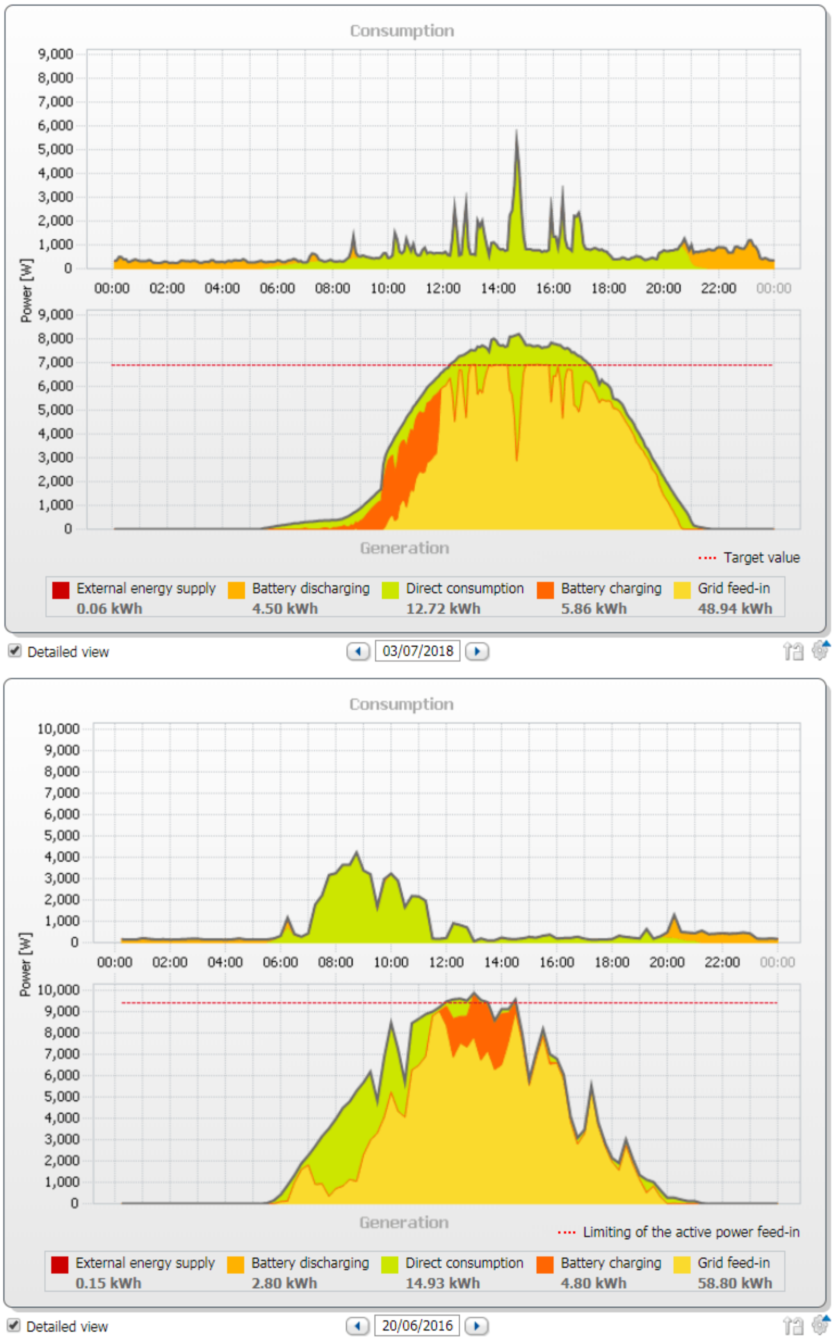
Emissions Reductions

Control strategies to reduce emissions

There is a range of opportunities from a BESS with appropriate control strategies to minimise grid emissions. The most common is the optimisation of solar PV self-consumption, which is the main financial driver for the installation of BESS with solar PV. This strategy by itself is likely to contribute to lower net GHG emissions from the grid, by reducing the higher evening grid emissions, even after accounting for the reduced offset emissions from exporting energy during the daytime (see approach 2).

The second strategy for reducing emissions relies on the ability to control the timing of BESS charging so that grid curtailment due to higher voltages is reduced or additional PV energy can be exported (see approach 1). This can be achieved by charging during the times when voltage is rising at the grid connection to close to the point when the inverter would reduce exports or completely disconnect (depending on the inverter). This type of control strategy is explored in research (von Appen and Braun, 2018; Gelleschus, Böttiger and Bocklisch, 2019) and supported by current products on the market (SMA, 2019) or patented (Procopiou, 2018). The control strategy is optimised by examining the forecast available solar resource for the coming day(s) and via learning of the daily loads, timing of export and export limits, targets the battery charging to occur when a there is a high likelihood of reaching export limits ,as shown in Figure 11. This example is a more extreme case study with large PV systems in Germany (which explains the mid-July segment examined).

Figure 11: BESS not optimised vs optimised to reduce export curtailment

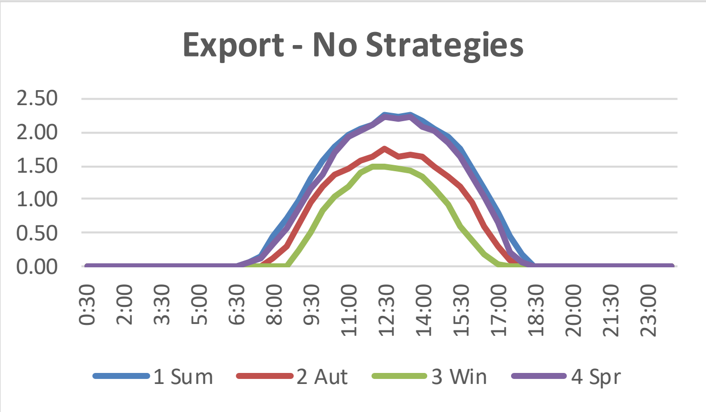


Source: (SMA, 2019)

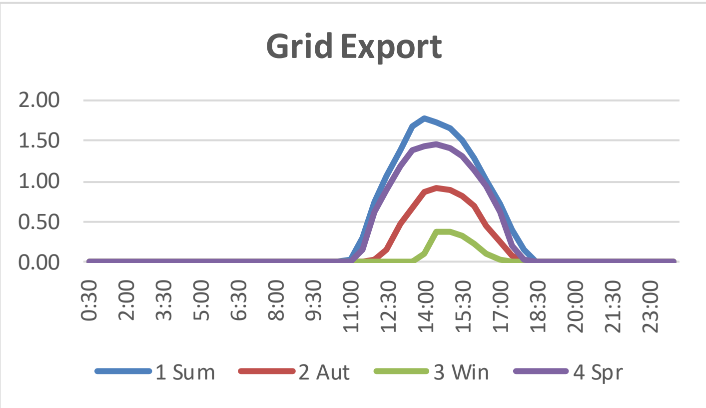
Distribution network operators or other aggregators could also control a fleet of BESS within a local area to simply charge the BESS at staggered times, with the diversified result providing an equivalent amount of additional PV hosting capacity. The diversity factor (which is used to determine the equivalent per site value of additional PV hosting) would depend on the size of the BESS/PV, loads of householders and local or regional grid constraints. This control methodology is assumed to be used for the calculation of the additional PV hosting capacity and amount of additional PV energy exported in the analysis used for this VEU opportunity.

This approach for the quantification of additional PV export involved a number of assumptions. The key assumption is the diversity factor that is applied and can not be easily determined unless the we know the individual grid constraints, the BESS sizes and loads of the households. However, assuming that a local grid has no additional PV hosting capacity and using average daily load profiles from the research conducted for the Victorian Default Offer (ACIL ALLEN, 2019), along with the size of a suitable BESS/PV system, it can be observed that approximately three systems would need to be controlled to enable most of the energy to be utilised behind the meter. This is shown in Figure 12.

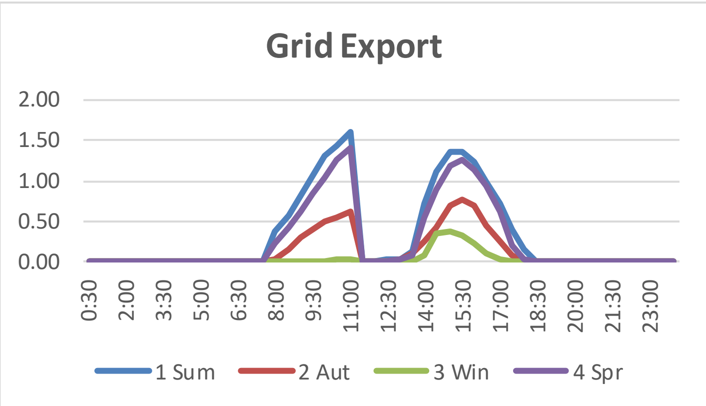
Figure 12: Grid export; no BESS, BESS with and without controlled timing of charging (kW by time of day)



No BESS



BESS with no control



BESS with control (11:00am)

Source: *EnergyConsult Simulation Model*; 5 kW PV, 12 kWh BESS, 4+ person HH, Melbourne with control of charging to 11 AM only occurring when sufficient solar resources are forecast for that day.

The analysis suggests that this simulation of BESS/PV with controlled charging to the middle of the day would eliminate most exports to the grid during the summer period when it is likely that grid voltage is highest (due to PV output being synchronised with solar resources) and enable either additional export (if these is no grid constraint) or utilisation of the curtailed exports (if there is a grid constraint on exports).

The assumed diversity factor is conservative (assuming the strategy requires 3 BESS/PV systems the diversity factor is 1/3 or 0.33). The additional energy that could be made available for export is 0.33 x the energy which is diverted to the HSW by the diverter (rather than exported), using this example of loads, HWS size and PV size.

Estimated potential emissions reduction

The estimated potential emissions reduction for a simulated household with BESS and PV is related to the PV system size, household energy use, and BESS size. The estimated emission reductions are shown in Table 8, using an example of 5 kW PV system, 12 kWh BESS and based on the average 4+ person household in Melbourne climate zone. The amount of emission reduction compared to a 5 kW PV system alone (no BESS) is estimated at 9.8 tonnes CO_2-e. These emissions reductions are based on a 10-year life, if installed in 2020, and use the hourly emissions intensity profile.

Table 8: Net GHG emissions over 10 years (t CO_2-e)

Situation	Approach 1	Approach 2	Total
5kW PV – No BESS	0.0	-1.8	-1.8
5 kW PV + 12 kWh BESS	0.0	-3.9	-3.9
5 kW PV + 12 kWh BESS + Controls	-7.7	-3.9	-11.6
Reduction compared to No BESS	**7.7**	**2.1**	**9.8**

The largest potential reduction is from approach 1, the ability to host more solar PV within the Victorian electricity grid. A smaller emission reduction is obtained by including approach 2, shifting of time when electricity is used and exported. Although it might not be attributable to the VEU, as this component (approach 2) of the of emissions reduction occurs without the control strategy, the VEU incentive may encourage greater uptake of the BESS, where customers are assessing all the benefits of installing a BESS, including electricity cost savings, demand response incentives and other government incentives. The demand response incentives are hard to quantify, as programs are still in the trial period, for example, AusNet are offering $15 per event to reduce load during this coming summer, with 10 events potentially applicable[13] in selected areas.

The estimated energy cost savings (for the example above of 5kW PV + BESS vs No BESS) is approximately $240 pa, which does not provide a significant return on approx. $10K of investment, however, when all the additional benefits and incentives are

[13] See https://mailchi.mp/ausnetservices/ggeoi

included, it might become more attractive. Further details of the methodology and assumptions of the simulation are provided in Energy Flow Simulation Model.

Influencing Factors

As indicated, there are various influencing factors, which are difficult to singular quantify, due to the inter-related impacts of each factor. The size of the battery is related to both the household energy consumption and the size of the PV system, which needs to be optimised for each household. In general, the larger the household energy consumption, the larger the required BESS energy storage capacity and the potential size of the PV system. However, there is optimal capacity points when additional capacity costs are not adding sufficient benefits. In addition, the ability to increase the hosting capability of the grid will be dependent on the local distribution system characteristics and amount of existing solar PV generation/export.

Another feature of this potential activity is that BESS can provide significant and quantifiable demand response when required, which can benefit the stability of the electricity grid and even potentially assist with decreasing energy prices.

Implementation Issues

This type of activity may be suitable for a measurement approach under the VEU, due to the high number of dependent factors affecting the potential emission savings. On the other hand, deemed activities may be suitable within certain boundaries, such as minimum household size (and energy use), PV size and BESS size. Assumptions could be tested with trials, that might already be underway (such as the ongoing project mentioned in the paper delivered at the Melbourne Energy Institute[14] (Procopiou, 2018)).

As explained earlier, the diversity factor is dependent on the system characteristics and household loads. The diversity factor effectively accounts for multiple sites when each site is contributing to the increased PV hosting capacity of the grid. If we assume that a smaller BESS and PV is installed that enables almost all the solar PV to be utilised BTM, the diversity factor is set to 1.0. An example of this situation (2.5 kW PV, 8 kWh BESS, 4+ person HH, Melbourne) shows that 98% of solar PV energy is consumed BTM, and the resultant emission reduction due to approach 1 is 7.8 t CO2-e, which is almost identical the earlier example. This provides some guidance to minimum conditions that can be used to determine a deemed value of emissions reduction and VEECs.

There are a number of aggregators and equipment/control suppliers that would may be approached to determine the market feasibility of this activity, such as:

- SMA (SMA, 2019)
- Reposit Power - https://repositpower.com/
- Tesla - https://www.tesla.com/en_AU/powerwall

[14] Also see https://electrical.eng.unimelb.edu.au/power-energy/projects/ and the Solutions for Increasing PV Hosting Capacity

- CarbonTrack - https://carbontrack.com.au/
- Solar edge - https://www.solaredge.com/aus/solutions/grid-services
- Sonnen - https://sonnen.com.au/

HWS, Diverter and Control Strategies

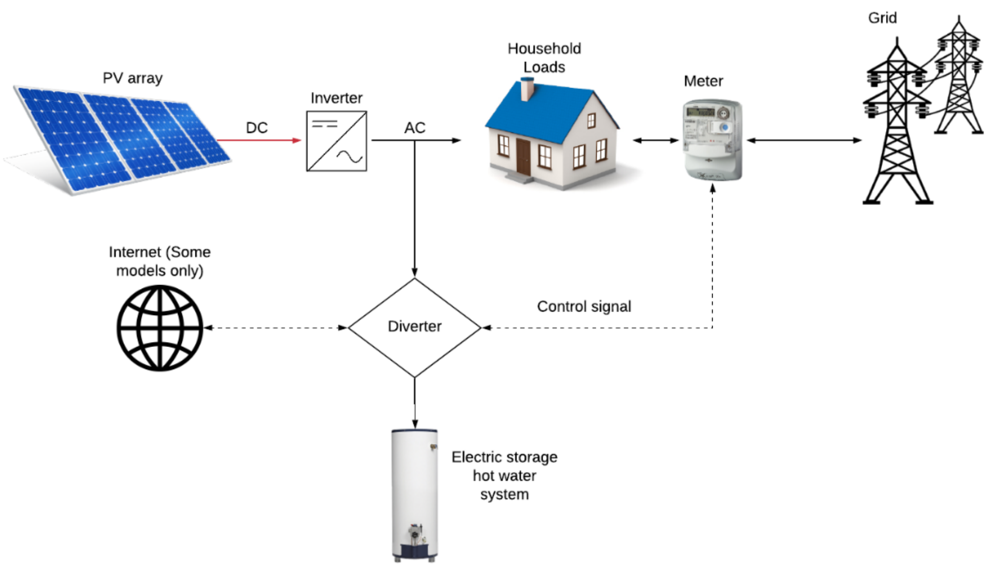
Description

Electric Hot Water Systems (HWS) are able to be controlled to use excess PV energy with equipment commonly called a “diverter”. The diverter is an enclosed power electronics device that controls the amount AC current to an electric storage water heater. They all require a sensor to indicate when energy is being exported (usually a current transformer on the grid side of the meter) to control when to turn the HWS element on and control amount of power drawn. Some also have a timer to ensure that off-peaks periods are used when solar PV is not sufficient to heat the HWS to the required temperature.

Under normal operation, the diverter will utilise excess solar as it becomes available during the day. For some diverters, they optimise the amount of PV used by examining the forecast weather conditions and predicting if there will be sufficient day ahead solar resources available to not use grid electricity the night before to heat the HWS.

The use of these types of diverters often include cloud-based monitoring of energy performance. An example of the hardware used for such a system is shown in Figure 13.

Figure 13: Basic elements of a HWS, diverter and controls



There are several suppliers of diverters which vary in features, some include the ability to optimise solar PV self-consumption by using forecasts of solar resources and not energising the HWS with grid electricity overnight[15].

The activity modelled for this opportunity involves installing a diverter with controls and automation to control an existing electric storage water heater. Ideally these systems are that are capable of being aggregated to control the timing of diverter timing for a fleet of systems. No suppliers have this feature however, some would have the capacity to undertake this type of control using existing hardware and cloud-based control.

In addition, the strategy has been modelled to only "delay" the timing of diverter operation depending on the forecast of day ahead solar resources and household energy consumption, and state of energy stored in the HWS. If the required HWS energy to reach thermostat temperature is less than 60% of the day ahead solar available forecast energy, the charging can be delayed. This is a simplified algorithm designed to ensure that sufficient excess solar will be able to meet the HWS required energy with part of the available solar, given the uncertainties of forecasting both available excess solar and energy usage. More sophisticated and complex algorithms or machine learning would actually be implemented in practice.

Emissions Reductions

Control strategies to reduce emissions

Similar to the BESS, there is a range of opportunities with appropriate control strategies to minimise grid emissions. The optimisation of solar PV self-consumption, is the main financial driver for the installation of the HSW diverter with solar PV. This strategy by itself is likely to contribute to lower net GHG emissions from the grid, by reducing the higher evening grid emissions, even after accounting for the reduced offset emissions from exporting energy during the daytime (see approach 2).

The second strategy for reducing emissions relies on the ability to control the timing of diverter based HWS element so that grid curtailment due to higher voltages is reduced or additional PV energy can be exported (see approach 1). This can be achieved by diverting the energy to the HWS during the times when voltage is rising at the grid connection to close to the point when the inverter would reduce exports or completely disconnect (depending on the inverter). No diverters on the market at this stage have this control feature, however if they are internet connected, the strategy should be viable. Diverters or the HWS could also be fitted with a demand response enabling device (DRED) which would enable the timing of the diverter/HWS activation as described in the recent consultation paper on smart demand response (E3, 2019).

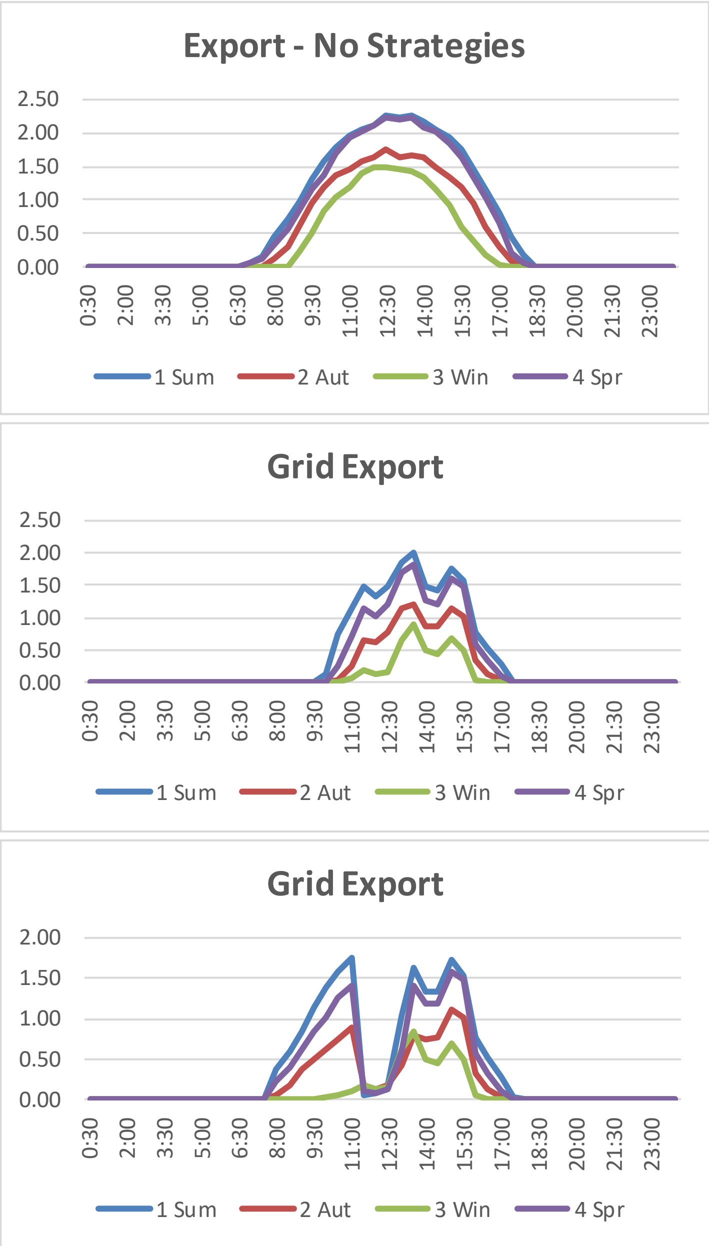
As for BESS, distribution network operators or other aggregators could also control a fleet of diverters/HWS within a local area to simply activate the HWS at staggered times, with the diversified result providing an equivalent amount of additional PV

[15] See https://www.catchpower.com.au/blue-catch/

hosting capacity. The diversity factor (which is used to determine the equivalent per site value of additional PV hosting) would depend on the size of the HWS, loads of householders and local or regional grid constraints. This control methodology is assumed to be used for the calculation of the additional PV hosting capacity and amount of additional PV energy exported in the analysis used for this VEU opportunity.

This approach for the quantification of additional PV export involved a number of assumptions. The key assumption is the diversity factor that is applied and cannot be easily determined unless the we know the individual grid constraints, the HWS/PV sizes and loads of the households. However, following a similar approach used for the BESS, it can be observed that approximately four systems would need to be controlled to enable most of the energy to be utilised behind the meter. This is shown in Figure 14.

Figure 14: Grid export; HWS no diverter, HWS/diverter with and without controlled timing of charging (kW by time of day)



HWS, No Diverter

HWS, with Diverter

HWS, Diverter with control (11:00am)

Source: *EnergyConsult Simulation Model*; 5 kW PV, 200 ltr HWS, 4+ person HH, Melbourne with control of activation to 11 AM only occurring when sufficient solar resources are forecast for that day.

The analysis suggests that this simulation of HWS/diverter/PV with controlled charging to the middle of the day would eliminate some exports to the grid during the summer period when it is likely that grid voltage is highest and enable either additional export (if these is no grid constraint) or utilisation of the curtailed exports (if there is a grid constraint on exports).

The assumed diversity factor is conservative (assuming the strategy requires 4 HWS/diverter/PV systems the diversity factor is 1/4 or 0.25). The additional energy that could be made available for export is 0.25 x the energy which is used by the HWS (rather than exported), using this example of loads, HWS size and PV size.

Estimated potential emissions reduction

The estimated potential emissions reduction for a simulated household with HWS and PV/diverter is related to the PV system size, household energy use/hot water use, and HWS size. The estimated emission reductions are shown in Table 9, using an example of 5 kW PV system, 200 ltr HWS and based on the average 4+ person household in Melbourne climate zone. The amount of emission reduction compared to a 5 kW PV system alone (no diverter/HWS) is estimated at 10.3 tonnes CO2-e. These emissions reductions are based on a 10-year life, if installed in 2020, and use the hourly emissions intensity profile.

Table 9: Net GHG emissions over 10 years (t CO2-e)

Situation	Approach 1	Approach 2	Total
5kW PV + HWS	0.0	18.8	18.8
5 kW PV + HWS/diverter	0.0	16.8	16.8
5 kW PV + HWS/diverter + Controls	-5.9	14.5	8.6
Reduction compared to No diverter/controls	**5.9**	**4.4**	**10.3**

The largest potential reduction is from approach 1, the ability to host more solar PV within the Victorian electricity grid. A significant emission reduction is also obtained by including approach 2, shifting of time when electricity is used and exported. Although it might not be attributable to the VEU, as a proportion of this component of the of emissions reduction occurs without the modelled control strategy, the VEU incentive may encourage greater uptake of the diverters, where customers are assessing all the benefits of installing a diverter, including electricity cost savings and other government incentives. Demand response incentives are unlikely to be offered for HWS as they are usually on a controlled or ToU tariff.

The estimated energy cost savings (for the example above of 5kW PV + HWS/diverter vs 5kW PV + HWS no diverter) is approximately $160 pa, which does provide a good return on approx. $1,000 of investment. Further details of the methodology and assumptions of the simulation are provided in Energy Flow Simulation Model.

Influencing Factors

As indicated, there are various influencing factors, which are difficult to singular quantify, due to the inter-related impacts of each factor. The size of the HWS and hot water usage, general household consumption impact on the appropriate size of the PV system, and needs to be optimised for each household. In general, the larger the household hot water consumption/HWS, the larger the potential size of the PV system. However, there is optimal capacity points when additional PV capacity costs are not adding sufficient benefits. In addition, the ability to increase the hosting capability of the grid will be dependent on the local distribution system characteristics and amount of existing solar PV generation/export.

Implementation Issues

This type of activity may be suitable for a deeming approach under the VEU, if suitable boundaries can be determined, such as minimum household size, hot water energy use or WHS size and PV size. Assumptions could be tested with trials, or obtaining data from suppliers who are monitoring sites in Victoria.

The approach used to determine the potential emission reduction for this opportunity assumes that an electric storage water heater is present in the home and is using an off-peak tariff. Therefore, no energy savings result from this strategy. The emissions reduction from installing a more efficient water heater (such as a heat pump water heater or electric boosted solar water heater) are not compared. A comparison of alternative options may show larger emissions reductions and it would be interesting to also compare the cost effectiveness of these alternative options from the perspective of the householder. Given that these alternative options are approved activities within the VEU, consideration of the impact of the diverter/controls strategy on the existing VEU activities would be valuable.

As explained earlier, the diversity factor is dependent on the system characteristics and household loads. The diversity factor effectively accounts for multiple sites when each site is contributing to the increased PV hosting capacity of the grid. If we assume that a smaller PV is installed that enables a significant amount of the solar PV to be utilised BTM by the HWS, the diversity factor is set to 1.0. An example of this situation (2.0 kW PV, 200 ltr HWS + diverter, 4+ person HH, Melbourne) shows that 95% of solar PV energy is consumed BTM, and the resultant emission reduction due to approach 1 is 5.1 t CO2-e, which is slightly lower than the earlier example. This provides some guidance to minimum conditions that can be used to determine a deemed value of emissions reduction and VEECs.

There are a number of equipment/control suppliers that would may be approached to determine the market feasibility of this activity, such as:

- Fronius (Fronius, 2018)
- AWS-Sunmate - https://www.australianwindandsolar.com/aws-sunmate
- Catch Power - https://www.catchpower.com.au/
- Paladin - http://www.paladinsolarcontroller.com.au/
- Power Diverter - https://www.powerdiverter.com.au/
- Rheem/Solahart - https://www.solahart.com.au/products/battery-storage/solahart-powerstore/. (Although this is a complete HWS, diverter and controls, so is suitable for replacement of failed Electric Storage HWS)

EVSE and Control Strategies

Description

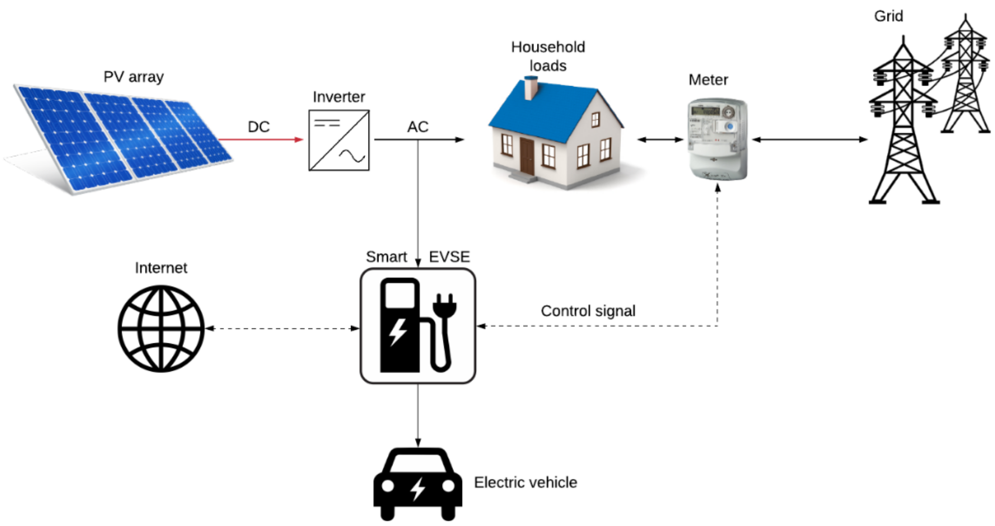
Electric Vehicles (EV) are able to utilise excess PV energy with "smart" electric vehicle supply equipment (EVSE). The terminology and specifications of EVSE is often confusing with various standards and plug types available. The report by the IEA 4E EDNA group provides a good summary of the standards that apply world-wide(IEA EDNA, 2017b). The EVSE is often described in terms of "Levels" using the USA standard US SAE J1772 or modes by the European standard IEC EN 61851-1. On top of these standards are the plug type, for connecting to the EV.

The EVSE that is most relevant for this opportunity is typically only available in dedicated EVSE, that is hard wired to the household switchboard. These are commonly called level 2. Level 2 has a maximin output of up to 19 kW.

The EVSE that is modelled for this opportunity controls the amount current to the on-board EV charger, depending on the excess energy being exported to the grid. They require a sensor to indicate when energy is being exported (usually a current transformer on the grid side of the meter) to control when to turn the EVSE on and control amount of power drawn. Some also have a timer to ensure that off-peaks periods are used when solar PV is not sufficient to meet the required EV load.

Using this strategy, the EVSE will utilise excess solar as it becomes available during the day. These types of EVSE often include cloud-based monitoring and control of energy supply settings. An example of the hardware used for such a system is shown in Figure 15.

Figure 15: Basic elements of an EVSE, with PV and controls



There are suppliers of EVSE which have these features, with most including a timer to limit the EVSE to certain times of the day instead of monitoring the flow of energy to the grid. At least on EVSE includes the ability to optimise solar PV self-consumption by using a current sensor at the meter.

The activity modelled for this opportunity involves adding installing a smart EVSE with controls and automation to control EVSE to use excess solar PV instead of a standard EVSE. Ideally these systems are that are capable of being aggregated to control the timing of EVSE timing for a fleet of systems. No suppliers have this feature however, some would have the capacity to undertake this type of control using existing hardware and cloud-based control or include a DRED with their existing EVSE product.

In addition, the strategy has been modelled to only "delay" the timing of ESVE operation depending on the forecast of day ahead solar resources and household energy consumption, and state of energy stored in the EV. If the required EV energy to reach full charge is less than 60% of the day ahead solar available forecast energy, the charging can be delayed. This is a simplified algorithm designed to ensure that sufficient excess solar will be able to meet the EV required energy with part of the available solar, given the uncertainties of forecasting both available excess solar and energy usage. More sophisticated and complex algorithms or machine learning would actually be implemented in practice.

Emissions Reductions

Control strategies to reduce emissions

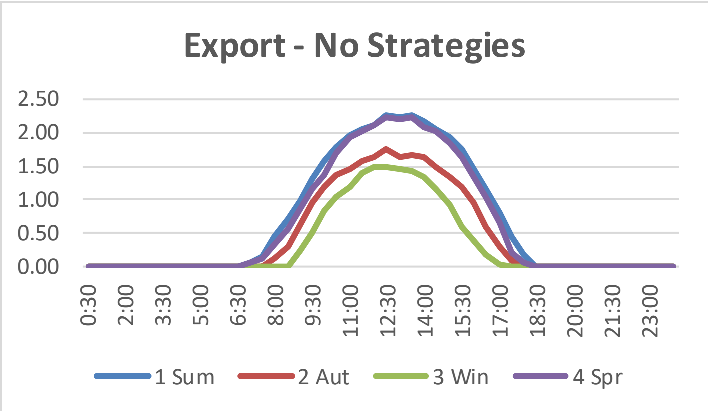
Similar to the BESS, there is a range of opportunities with appropriate control strategies to minimise grid emissions. The optimisation of solar PV self-consumption, is the main financial driver for the installation of the smart EVSE with solar PV. This strategy by itself is likely to contribute to lower net GHG emissions from the grid, by reducing the higher evening grid emissions, even after accounting for the reduced offset emissions from exporting energy during the daytime (see approach 2).

The second strategy for reducing emissions relies on the ability to control the timing of EVSE operation so that grid curtailment due to higher voltages is reduced or additional PV energy can be exported (see approach 1). This can be achieved by diverting the energy to the EV during the times when voltage is rising at the grid connection to close to the point when the inverter would reduce exports or completely disconnect (depending on the inverter). No EVSE on the market at this stage have this control feature, however if they are internet connected, the strategy should be viable. The EVSE could also be fitted with a demand response enabling device (DRED).

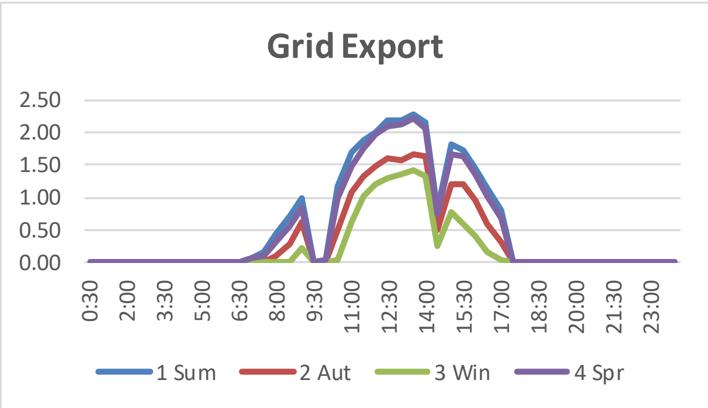
As for BESS, distribution network operators or other aggregators could also control a fleet of EVSE within a local area to simply activate the EVSE at staggered times, with the diversified result providing an equivalent amount of additional PV hosting capacity. The diversity factor (which is used to determine the equivalent per site value of additional PV hosting) would depend on the size of the battery in the EVSE, EV usage, loads of householders and local or regional grid constraints. This control methodology is assumed to be used for the calculation of the additional PV hosting capacity and amount of additional PV energy exported in the analysis used for this VEU opportunity.

This approach for the quantification of additional PV export involved a number of assumptions. The key assumption is the diversity factor that is applied and cannot be easily determined unless the we know the individual grid constraints, the EV/PV sizes, EV usage, EV parking and loads of the households. However, following a similar approach used for the BESS, and considering that there is a high level of uncertainty regarding the parking location and user behaviour it is assumed that approximately ten systems would need to be controlled to enable most of the energy to be utilised behind the meter. This is shown in Figure 16.

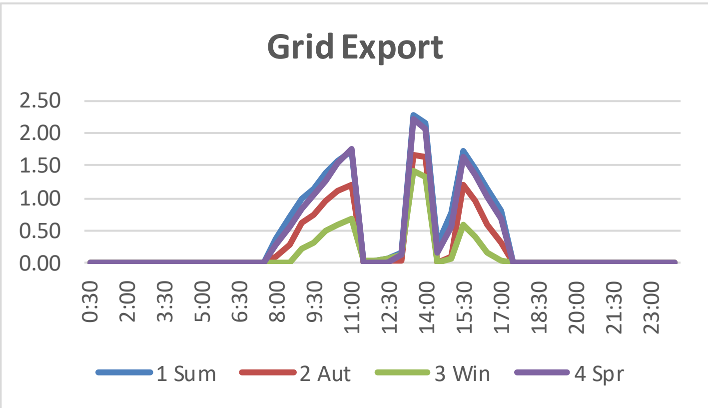
Figure 16: Grid export; EVSE standard, smart EVSE with and without controlled timing of charging (kW by time of day)



EV, standard EVSE



EV, with smart EVSE



EV, smart EVSE with control (11:00am)

Source: *EnergyConsult Simulation Model*; 5 kW PV, medium EV, home during the day, 4+ person HH, Melbourne with control of activation to 11 AM only occurring when sufficient solar resources are forecast for that day.

The analysis suggests that this simulation of EV/EVSE/PV with controlled charging to the middle of the day would eliminate some exports to the grid during the summer period when it is likely that grid voltage is highest and enable either additional export (if these is no grid constraint) or utilisation of the curtailed exports (if there is a grid constraint on exports).

The assumed diversity factor is conservative (assuming the strategy requires 10 EV/EVSE/PV systems the diversity factor is 1/10 or 0.10). The additional energy that could be made available for export is 0.10 x the energy which is used by the EV (rather than exported), using this example of loads, EV usage and PV size.

Estimated potential emissions reduction

The estimated potential emissions reduction for a simulated household with an EV and smart EVSE is related to the PV system size, household energy use/EV use, and EV parking location. The estimated emission reductions are shown in Table 10, using an example of 5 kW PV system, medium EV usage (14,600 km/yr), evening charging and based on the average 4+ person household in Melbourne climate zone. The amount of emission reduction compared to a 5 kW PV system alone (no smart EVSE) is estimated at 4.9 tonnes CO2-e. These emissions reductions are based on a 10-year life, if installed in 2020, and use the hourly emissions intensity profile.

Table 10: Net GHG emissions over 10 years (t CO2-e)

Situation	Approach 1	Approach 2	Total
5kW PV + EV and EVSE -standard	0.0	15.5	15.5
5 kW PV + EV and EVSE – smart	0.0	13.8	13.8
5 kW PV + EV and EVSE – smart and controls	-2.3	12.9	10.6
Reduction compared to EVSE standard	**2.3**	**2.6**	**4.9**

The emissions reduction from approach 1, the ability to host more solar PV within the Victorian electricity grid, is similar to the emission reduction is also obtained by including approach 2, shifting of time when electricity is used and exported. Although it might not be attributable to the VEU, as a proportion of this component of the of emissions reduction occurs without the modelled control strategy, the VEU incentive may encourage greater uptake of the smart EVSE, where customers are assessing all the benefits of installing a smart EVSE, including electricity cost savings and other government incentives. Demand response incentives also potentially could be offered smart EVSE to avoid EV charging at peak times and encourage more off-peak charging.

The estimated energy cost savings (for the example above of 5kW PV + smart EVSE vs 5kW PV + standard EVSE) is approximately $130 pa, which does provide a significant return on approx. $100 of additional investment. Further details of the methodology and assumptions of the simulation are provided in Energy Flow Simulation Model.

Influencing Factors

As indicated, there are various influencing factors, which are difficult to singular quantify, due to the inter-related impacts of each factor. The size of the EV, EV usage/charging times and general household consumption impact on the appropriate size of the PV system, which needs to be optimised for each household. In general, the larger the usage of the EV, the larger the potential size of the PV system. However, there is optimal points when additional PV capacity costs are not adding sufficient benefits. In addition, the ability to increase the hosting capability of the grid will be dependent on the local distribution system characteristics and amount of existing solar PV generation/export.

Implementation Issues

This type of activity may be suitable for a deeming or measurement approach under the VEU, if suitable boundaries can be determined, such as minimum household size, EV use, charging times and PV size. Assumptions could be tested with trials.

The approach used to determine the potential emission reduction for this opportunity does not account for the potential emission reduction from using an EV compared to an internal combustion engine (ICE) vehicle. As the VEU is not incentivising the purchase of EVs, there are no attributed emissions reductions due to the purchase of EVs over ICE vehicles.

The estimated emissions reduction is highly related to the ability of the householder to charge the car during the day time at home, which is not typical of most car usage. 60 to 70% of trips are reported as commutes away from home to work/school etc (Evenergi, 2019). Further, the total distance travelled by private vehicles for work in Victoria is 40 million km, out of a total of 80 million km per year (Department of Transport Victoria, 2016). Also – there is a high degree of viability in usage characteristics, with some studies suggesting only 14 to 20 km of travel a day, which means that the storage capacity of the EV is relatively small (3 – 4 kWh), hence the ability to utilise excess solar is also reduced. It is more likely that larger travel distances are closely associated with a work commute, which reduces the ability to charge during the day at home. Further analysis of the Victorian Integrated Survey of Travel & Activity (Department of Transport Victoria, 2016) could be undertaken as it is provided as a CSV file, which could be used to assess the purpose of trips, vehicle locations and suitability for EV/EVSE control and solar PV BTM optimisation.

The modelling has not examined the potential for using a BESS with an EV to increase the solar self-consumption overall (instead of relying on daytime parking of the EV at home). This would increase the emissions reduction potential and align with more common driving/parking patterns of behaviour. The additional use of the BESS would also increase losses, but these may be outweighed by the emissions reductions and cost savings for the household. Further investigation of this approach may be warranted.

There are a number of equipment/control suppliers that would may be approached to determine the market feasibility of this activity, such as:

- Zappi (solar optimised smart EVSE) https://www.zappi.info/en/
- Wallbox (wifi connected, scheduling and control) - https://wallbox.com/en_catalog/
- Jet Charge (supplier of several EVSE) https://jetcharge.com.au/
- EVSE.com.au (supplier of several EVSE), also have a solar PV EVSE solution – Mini Pro, https://evse.com.au/home-ev-charging/

AC Pre-cooling

Description

The concept of this strategy is to pre-cool houses (which already have existing AC) by using excess solar PV energy to run AC earlier than otherwise, on suitable days that will be likely have AC cooling demand in the later part of the day. The aim is to reduce cooling loads within the house, effectively using the thermal inertia of the house structure and contents, and hence reduce the AC operation in the later part of the day/evening. The strategy would be likely to increase energy consumption, as the house will not retain all the input cooling energy due to solar heat gains, cooling energy losses and infiltration., as well as the additional energy input to cool the house over the pre-cooling period that would not be otherwise undertaken.

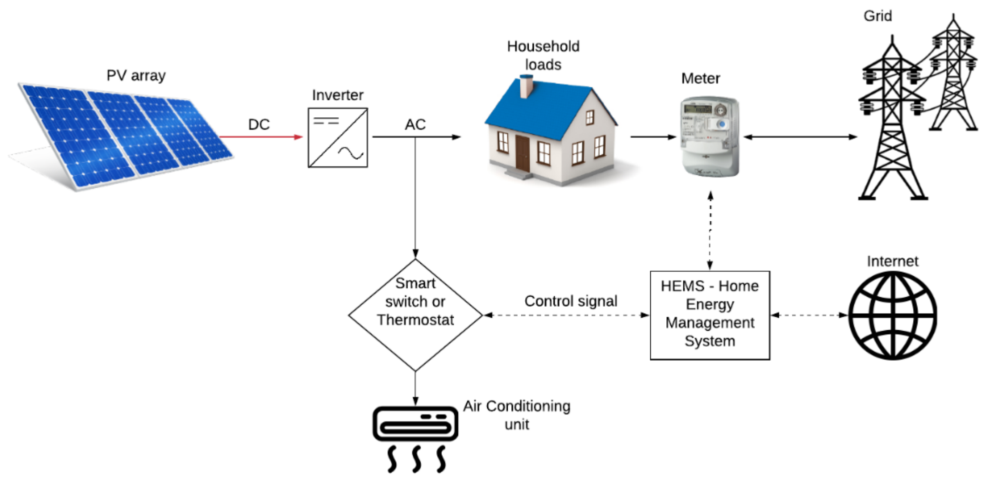
This concept has been applied in simulations of residential situations and the ability to reduce grid demand in the early evenings within the research conducted at the University of Melbourne (Jazaeri, Alpcan and Gordon, 2018, 2019). These authors have also explored the impact building wall types, and found that higher thermal mass walls will decrease the amount of peak cooling loads (Jazaeri, Gordon and Alpcan, 2019). This research shows that pre-cooling can potentially enable the AC unit to be turned off for a period of one hour during peak demand events without increasing the inside temperatures above the comfortable zone, in common brick veneer constructed houses.

To examine the potential for pre-cooling, a simplified thermal model of the house was developed by the key author of these University of Melbourne research papers (J. Jazaeri) specifically for this project. It is used to evaluate the potential of this concept to shift the energy used in AC cooling of a representative house and determine the overall emissions under Melbourne climate conditions. Further details are found in Energy Flow Simulation Model.

The concept that is modelled for this opportunity involves the control of the AC unit by a Home Energy Management system or cloud-based control platform, that operates the AC unit, depending on the excess energy being exported to the grid. It would require a sensor to indicate when energy is being exported (usually a current transformer on the grid side of the meter) to provide the signal to control when to turn the AC unit on and by temperature set points, control amount of power drawn. It is likely to implemented by a smart switch (to turn the AC on/off) and a connected IR replicator to control thermostat. The functions could also be implemented by a smart thermostat (which is readily able to perform this type of control). AC units themselves may develop to be controlled in this way, as they are increasingly becoming internet connected.

Using this strategy, the AC will utilise excess solar as it becomes available during the day. An example of the hardware used for such a system is shown in Figure 17.

Figure 17: Basic elements of an Smart AC, with PV and controls



Smart thermostats are now being used in grid demand response programs in the USA[16] and by integrating with inverters[17]. However, this specific control strategy has not been trailed in Australia, but is suggested by the Renew organisation (Renew, 2018).

Emissions Reductions

Control strategies to reduce emissions

Similar to the BESS, there is a range of opportunities with appropriate control strategies to minimise grid emissions. The optimisation of solar PV self-consumption, is the main financial driver for the installation of this type of AC control with solar PV. This strategy however did not result in lower net GHG emissions from the grid, as the for the reduction in offset emissions from exporting energy during the daytime, did not outweigh the reduced evening grid emissions (see approach 2).

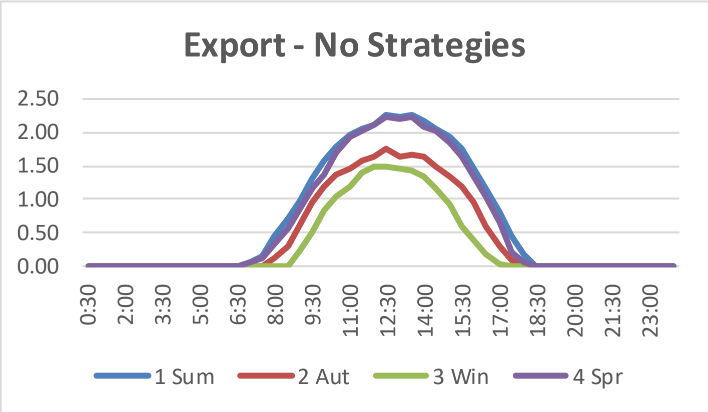
The second strategy for reducing emissions relies on the ability to control the timing of AC so that grid curtailment due to higher voltages is reduced or additional PV energy

[16] https://www.greentechmedia.com/articles/read/leap-and-nest-team-up-on-smart-thermostat-to-energy-market-integration#gs.4v6se2
[17] https://enphase.com/en-us/works-with-nest

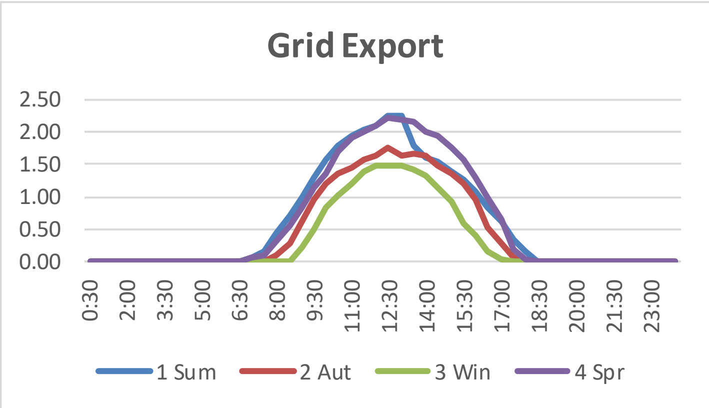
can be exported (see approach 1). However, very few opportunities for this approach occur as the pre-cooling energy use is not significant and only match the period of excess solar PV some of the time.

As shown in Figure 18, the impact is visible for summer, with an average 0.5 kW reduction in the afternoon.

Figure 18: Grid export; normal AC and with pre-cooling control (kW by time of day)



AC, normal operation



AC with pre-cooling control

Source: *EnergyConsult Simulation Model*; 5 kW PV, 150 m^2 cooling area, 4+ person HH, Melbourne. Set to operate normally from 4 pm to 10 pm, thermostat comfort range setting 17 to 24 ºC. Pre-cooling from 1 pm

The analysis suggests that this simulation of AC/pre-cooling/PV with would eliminate a very small amount of exports to the grid during the summer period. There may be some local benefits depending on the grid conditions, however this will be very specific to the area. AC energy consumption due to the strategy increases to 276 kWh pa compared to 160 kWh pa under normal operation. This also indicates that only a small amount of potential cooling energy is available for PV export reduction.

Estimated potential emissions reduction

The estimated potential emissions reduction for this strategy is shown in Table 11. This is based on an example of 5 kW PV system, 150 m^2 cooling area, 4+ person HH, with AC set to operate normally from 4 pm to 10 pm, a thermostat comfort range setting of 17 to 24ºC and the pre-cooling set to operate from 1 pm if required (and there is available excess solar PV being exported). The emission reduction compared to normal operation is negative 0.6 tonnes CO2-e, i.e., an increase in emissions. These emissions calculations are based on a 10-year life, if installed in 2020, and use the hourly emissions intensity profile. Therefore, the strategy is not suitable to be utilised in the VEU.

Table 11: Net GHG emissions over 10 years (t CO_2-e)

Situation	Approach 1	Approach 2	Total
5kW PV + AC	0.0	-0.9	-0.9
5 kW PV + AC with pre-cooling controls	0.0	-0.3	-0.3
Reduction compared to No pre-cooling	**0.0**	**-0.6**	**-0.6**

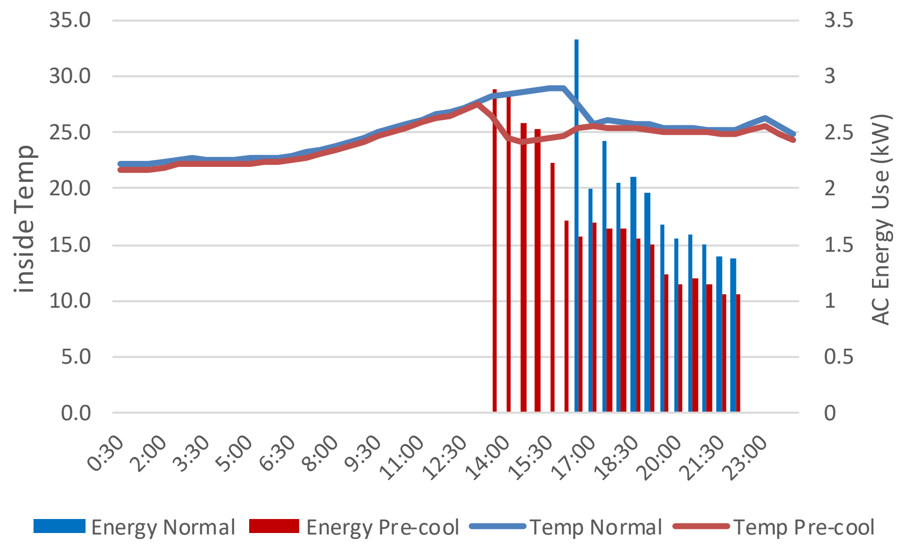
No benefit is calculated for approach 1, as the ability to reduce exports under controlled conditions is considered insignificant. Further details of the methodology and assumptions of the simulation are provided in Energy Flow Simulation Model.

Influencing Factors

As indicated, there are various influencing factors, which are difficult to singular quantify, due to the inter-related impacts of each factor. The size of the cooled area, occupancy/behaviour, thermal properties of the house and general household consumption impact on the appropriate size of the PV system.

The delay in operation and hence energy use of the AC unit that the pre-cooling can deliver is about one hour, using the thermal properties of a standard constructed house. There is not sufficient thermal inertia in this type of house to enable significant delays or reduction in the operation of the AC unit, as shown in Figure 19 for an example day in January

Figure 19: Normal vs Pre-cool inside temperature and energy for an example day



If the house was highly sealed, has many tonnes of internal thermal mass, is highly insulated with very small solar heat gains, there might be opportunities. However, in this case, the house is not likely to demand significant cooling.

One further area that could be investigated is the use of a BESS, instead of the thermal inertia to supply the AC unit in the evening, which is likely to be more efficient and reduce the losses associated with the pre-cooling strategy.

Energy Flow Simulation Model

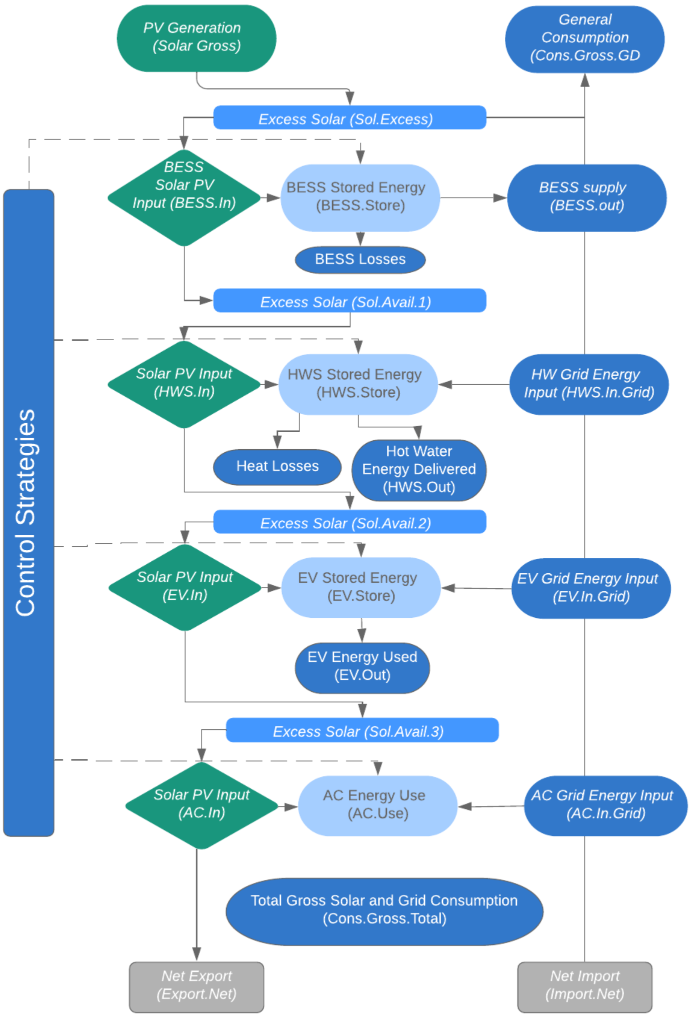
An energy flow simulation model was developed for this project to assess the emission reduction potential of a number of BTM control strategies which integrate with solar PV. The key features of the model are:

- Utilises 48 half-hour energy intervals for each day of the year to accurately assess the timing and amount of energy flows within a typical household
- Uses emission intensity profile of Victorian grid electricity by hour of the day and quarter, from 2020 to 2045 (supplied by DELWP) to assess the net GHG emissions over periods of time due to both shifting loads and increase/decrease in grid imports/exports
- Uses typical daily/weekday/weekend and seasonal energy use profiles developed for the Essential Service Commission (ACIL ALLEN, 2019) to characterise average energy use by climate zone and household size (three sizes; 1 person, 2-3 person and 4+ person households)
- Includes Solar PV generation profiles for Victoria used in the Renew (formally ATA) tool Sunulator[18] (currently only Melbourne is set up in the model)
- Includes four BTM strategies, that can be compared individually or together, and accounts for energy losses within each of the BTM systems (such as round trip efficiency for BESS, EV charger efficiency, heat losses of electric HWS, etc)

The model evaluates 17,520 ½ hour intervals (48 x 365) of energy flows simultaneously across all the key energy systems to enable virtually instant outputs when input parameters are changed. The model schematic is shown in Figure 20.

[18] See https://renew.org.au/resources/sunulator/

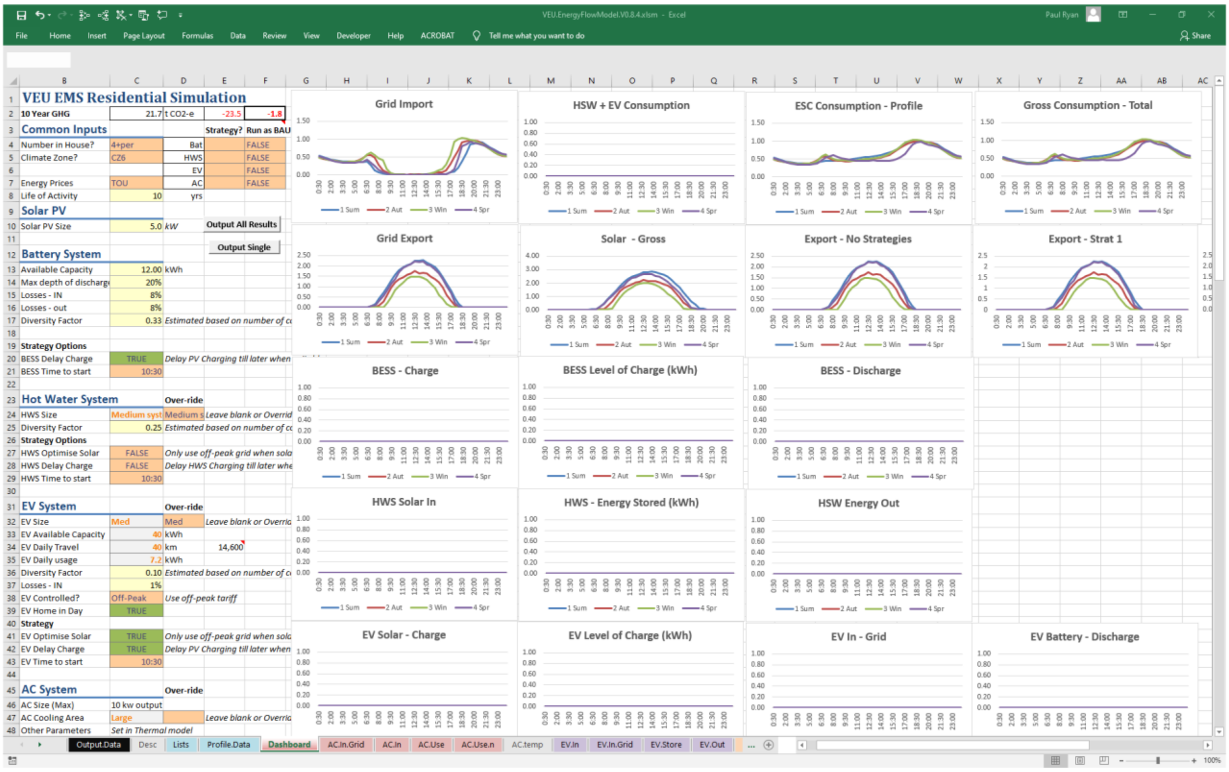
Figure 20: Energy flow simulation model schematic



Note: brackets (i.e., Solar.Gross) indicate the sheet name in the excel model representing the 48 x 365 periods of energy being evaluated

The model is flexible to address many different scenarios and users can observe the impacts for each energy system in detail, as shown in Figure 21.

Figure 21: Dashboard and control panel for energy flow simulation model



The model can accept various inputs including:

- Solar PV size (kW)
- BESS characteristics (storage capacity - kWh, Max depth of discharge, Losses) and control strategy (normal, delayed charging and time to start charging when forecast solar resources are sufficient)
- HWS size and control strategy (normal, optimise solar, delay charging and time)
- EVSE and EV size/usage characteristics and control strategy (normal, off-peak only, evening, optimise solar, delay charging and time
- AC system, cooling area, thermal characteristics of the house, temperature set points and control strategy (normal, pre-cooling, time to start, outside/inside temperature control)

Table 12 shows the model outputs and their description.

Table 12: Energy flow simulation model outputs and description

Output	Description
General Summary - Totals	
Generation - Gross	kWh generated
Consumption - Gross	kWh by tariff period (peak, off peak)
Grid - Export	kWh net exported
Grid - Import	kWh by tariff period (peak, off peak)
Solar Self Consumption	kWh consumed
Solar Self Consumption %	Proportion of solar consumed BTM
Total % Solar	Proportion of solar of total consumption
BESS	
BESS In	kWh used by BESS
BESS Out	kWh discharged
BESS Losses	kWh losses
BESS Round Trip Efficiency	% round trip efficiency
HWS	
HWS Total	kWh by tariff period (peak, off peak)
HWS % Solar	Proportion solar consumed of HWS total
EV	
EV Total	kWh by tariff period (peak, off peak)
EV % Solar	Proportion solar consumed of EV total
AC	
AC Total	kWh by tariff period (peak, off peak)
EV % Solar	Proportion solar consumed of AC total
GHG Emissions (life t CO2-e by yr installed)	
GHG - Grid	Grid import emissions
GHG - Offset	Grid exported emissions offset
Net GHG	Net Grid emissions
Annual Energy Costs	
Total cost	Total energy costs
Peak cost	Peak energy costs
Off Peak cost	Off-peak energy costs
Export benefit	Export energy credit
Peak energy	kWh
Off Peak energy	kWh
Export energy	kWh
Peak rate	Tariff in $/kWh (value is an input)
Off Peak rate	Tariff in $/kWh (value is an input)
Export Rate	Tariff in $/kWh (value is an input)

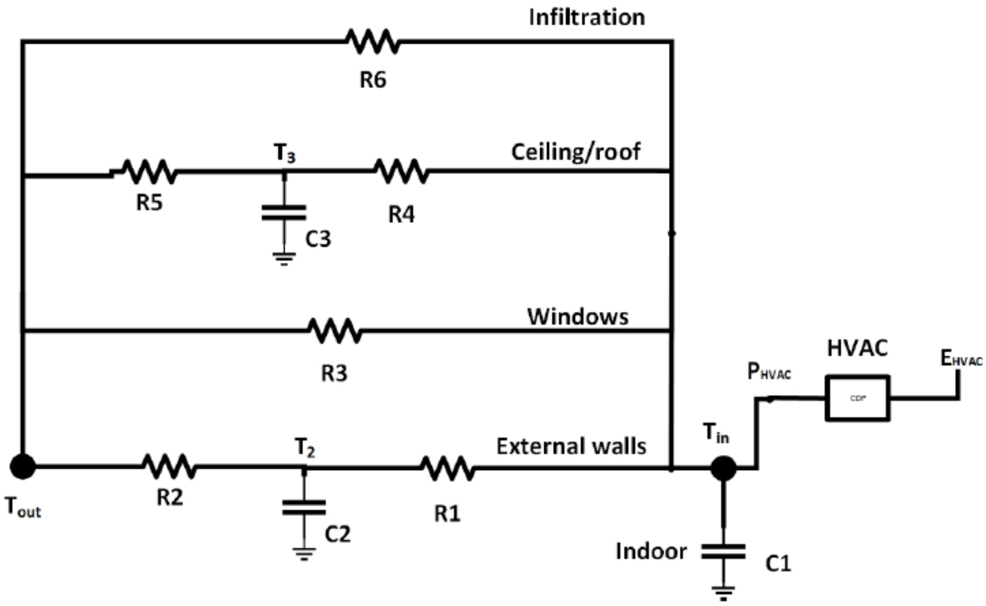
The model outputs are used to assess the BTM strategy in normal (BAU) operation and in modes with the selected control or input parameter.

The key inputs and assumptions are:

- Household energy use profile from the ESC for each household size
- BESS, assumes Li-ion, with round trip efficiency of 85% and max depth of discharge of 20%
- Solar PV – *Sunulator* outputs for Melbourne
- EV – Small, Medium and large,
  - Daily usage of 20, 40 and 80 km/day, 40 km/day is used for all simulations and equals 14,600 km/yr, which is close to the Victorian average of 13,600 km (ABS 2018)
  - EVSE max charge 2.4, 3.6 and 6 kW, which matches standard EVSE standards
  - EV efficiency is 0.180 kWh/km (Renew 2019).
- HWS, standard electric storage water heater, with MEPS heat losses for 125, 200 and 315 litres. Loads and draw profile are same as AS/NZS 4234 for Melbourne. Max load is set to Medium load for most simulations, which is more representative of hot water use.
- AC and thermal loads – Melbourne TMY weather data, cooling area of 50, 100 and 150 m^2. House characteristics: concrete slab floor with brick veneer, and standard insulation, infiltration. [described in attachment xxx]
- Energy prices, Average of Melbourne default offers for general and time of use (ToU) rates in 2019. The ToU rate is used by default as this would be required to obtain the maximum benefit of most control strategies. Feed-in tariff is set to 0.12/kWh, the current ESC regulated value. These prices are held constant for the 10 year life of the measure.
- Average life is set to 10 years for all the calculations, as this is the accepted minimum life for BESS, HWS, EVSE and AC. Although there might be situations when the controls are replaced earlier, we assume that similar control strategies will be operated.

The thermal module of the representative house was constructed in Excel and is connected to the Energy flow simulation model by direct linkages, including cooling area, excess PV available to the AC unit and resulting total AC unit energy use. The thermal module was developed by Dr J. Jazaeri with engineering calculations involving the thermal and electrical properties of the building and thermodynamics. Each element of the building is described in sets of parameters representing the heat transfer pathways by resistances (Ri) and building components with high thermal inertia are represented by capacitances (Ci), as shown in Figure 22. In addition, solar gains are also included. The principles of the model are described in the paper presented at the IEEE Transactions on Smart Grid (Jazaeri, Alpcan and Gordon, 2019). The module is implemented in Excel rather than TRNSYS, which reduces the accuracy, however is sufficient for testing the control concepts for this project. Further details of the thermal module are provided in a separate attachment.

Figure 22: Building thermal model representation



The thermal module can utilise various occupancy periods, thermostat settings and AC control settings. This enables the comparison of normal operation with the specified control strategy.

Inputs for VEU opportunity projection for period 2020 -2025

The key additional inputs, assumptions and sources for the VEU projected activities related to these EMS strategies are shown in Table 13 and Table 14.

Table 13: EMS strategy inputs

Input	Source or Value	Notes
Victoria Market Size 2020 -2030		
BESS stock projections	AEMO (AEMO, 2019)	Projections for Victoria contained in the file: 2019-Input-and-Assumptions-workbook.xlsx, Embedded energy storages, central scenario
HWS stock	DELWP CBA and RIS 2018 (EnergyConsult, 2018)	Stock is from the Medium and Large ESWH
Electric Vehicle stock projections	AEMO (AEMO, 2019)	Projections for Victoria contained in the file: 2019-Input-and-Assumptions-workbook.xlsx, Sheet Electric Vehicles, central scenario
PV Stock	AEMO (AEMO, 2019)	The measures assume the max uptake must be below the stock of PV households
Technology take up (BAU)	**Max penetration in 2030 (under VEU)**	S-curve function used to model penetration with variables for year and %
BESS + controls	80% of Stock of BESS u	Estimated based on current trends and costs to retrofit
HWS + Diverter/controls	25%	Estimated, limited by number of HWS which have PV
EV + smart EVSE/controls	20%	Estimated, limited by number of EVs that are home and can be charged during the day with excess PV

Table 14: Estimated costs of EMS strategy activities

Activity	Estimated Costs	Source/Notes
Residential		
BESS, just the controls	Incremental cost of $100, plus $20 pa ongoing service fee	Most BESS systems will be capable of the control strategy without any extra equipment or installation costs
HWS, just the Diverter/controls	$1,100 per product, plus $20 pa ongoing service fee	Estimated from supplier prices, including installation for the diverter and controls
EVSE, incremental cost of smart EVSE/controls	Incremental costs of $100, compared to a standard EVSE	Estimated from supplier prices for “smart” connected EVSE vs standard EVSE