# Transitioning Bendigo's energy economy - a feasibility study of renewable energy transition across an entire regional city

**Project summary report: June 2022**

**Prepared by Solar Energy Application Lab, RMIT University**

# Project Consortium

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LEAD AND AUTHORS OF THIS REPORT

YANG, Rebecca Jing; LIU, Chengyang; GUNARATHNA, Chathuri; WANG, Kaige; SUN, Chayn; ROSENGARTEN, Gary; WAKEFIELD, Ron

PARTNERS

C4NET, Centre for New Energy Technologies

City of Greater Bendigo

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Correspondence

Associate Prof. Rebecca Yang Email: rebecca.yang@rmit.edu.au

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# Executive Summary

**Background**

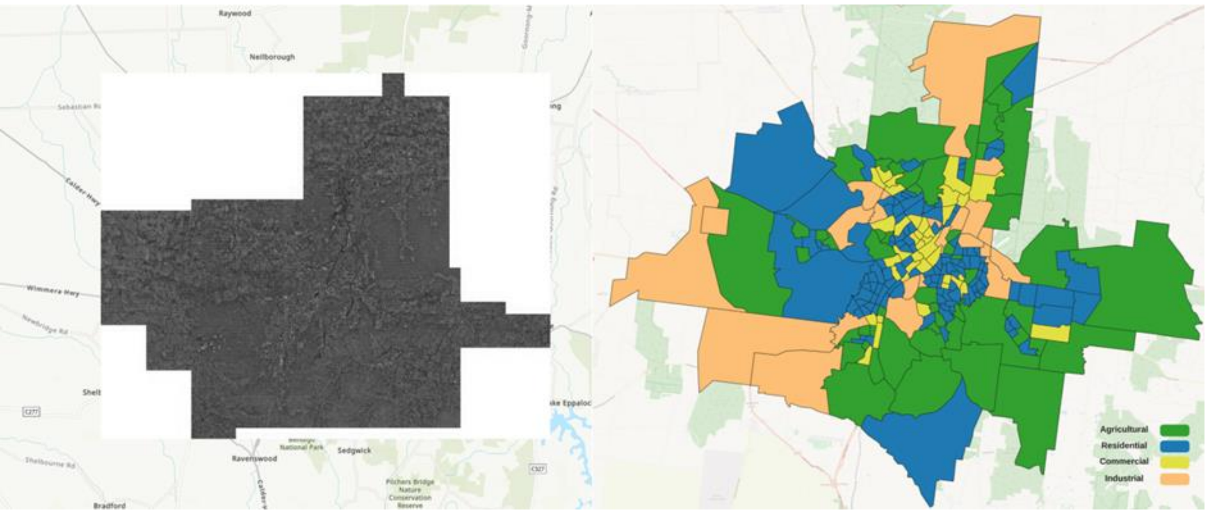
The Greater Bendigo City Council (the Council) has a strong commitment towards a renewable energy transition both for the operations of the City of Greater Bendigo (the City) and for the municipality and wider region.

Council's revised Climate Change and Environment Strategy 2021-2026 expresses targets to achieve zero carbon in the City's operations by 2030 and zero carbon across the Greater Bendigo municipal community by 2030. The Strategy includes a target for 500% of the municipality's 2021 energy demand to be generated through local renewable energy by 2036.

The study area was 235 'statistical area 1s' (SA1s) in Bendigo's urban and peri-urban area that had LiDAR coverage.

Bendigo, as the regional centre and with the abundant solar potential and the rapid update of renewable resources such as rooftop PV, has the potential to become a crucial driving force in the implementation of the Central Victorian Greenhouse Alliance (CVGA) Loddon Mallee Renewable Energy Roadmap (the Roadmap).

The Roadmap provides a snapshot of the opportunities and obstacles the region faces as it moves to a decentralised renewable electricity energy system.




LiDAR coverage in City of Greater Bendigo (Left) and the studied SA1s in this project (Right)

This Renewable Community Energy Transition (RCET) project aims to support the City's leadership of the community transition to zero carbon and local renewable energy resources. It investigates the opportunities and challenges, within the study area, of:

- Increasing the overall percentage of roof top area with solar panels, and
- Introducing community renewable energy retail and generation through two types of management strategies, namely Virtual Power Plant (VPP) and Peer-to-Peer (P2P) community renewable energy trading.

This report is in three sections:

1) Scope and Objectives

2) Research Design and Process

3) Findings, Observations and Outputs

**Issues**

The key findings, recommended actions and advocacy opportunities are summarised below:

(1) The current rooftop PV coverage percentage in the study area is around 1.73% of the total rooftop area.

(2) Among the four property types, the percentages of the properties that have PV installed are: residential: On average, 27.94% of properties within the study area of the project have installed PV systems[1], which is close to the APVI estimation of solar PV status (approx. 27.3% of dwellings).

**(3) To achieve a significant renewable energy transition, the priority for Bendigo is to fast track the installation of solar PV and home/community battery system capacity.**

Ideally, a PV growth rate of 132.5 MW/year (Current total installed capacity: 93 MW) will achieve the 50% - 70% carbon emission reduction for the municipality in 10 years' time. With an example of a PV unit that has $2m^2$ size or 400-Watt DC capacity, this growth rate is equivalent to 331 thousand units per year.

(4) For battery systems, the ideal growth rate is around 7,800 units/year. Using the TESLA Powerwall battery system as an example with usable capacity of over 10 kWh/unit, this growth rate equivalent to around two in ten households installing a battery unit per year.

(5) At the ideal PV growth rate (132.5 MW/year), the rooftop PV coverage could reach medium PV coverage scenario (25% rooftop area PV coverage – equivalent capacity: 752 MW) in 5 years, which will cover around 4,396,605 m2 of the rooftop and have a total generation of 718.50 GWH.

(6) With the 132.5 MW/year ideal growth rate, in 10 years, the rooftop PV will cover a rooftop area of 8,793,210 m2 (50% rooftop PV coverage - equivalent capacity: 1.54 GWH) and produce 1,437 GWH electricity per year. Although in both 25% and 50% rooftop coverage scenarios, the rooftop PV can generate a mass amount of electricity over the year, due to the unmatched demand and PV output, the demand offset ratios for these scenarios are 35.27% and 40.52% respectively.

[1] The findings (1) and (2) are estimated based on the Bendigo's LiDAR geospatial data provided by DELWP, Victoria Government (measurement time: March 2020). This research adopted an image recognition approach to identify the rooftop solar panels. The LiDAR coverage and study area are shown in Section 2.2.2.

**(7)** Bendigo's solar PV potential could substantially provide the community's electricity needs in the near future. **To do this, Bendigo needs significant expansion in rooftop PV and battery systems, with 132.5 MW/year for rooftop PV and 7,800 units/year for BESS (unit capacity of 13.5 kWh). At this rate, the community will offset demand by 48.36% in 5 years and 67.98% in 10 years.**

**(8)** The below communities are considered suitable for trialling VPP systems as they have higher socioeconomic scores and higher forecasted net present value when deploying VPP:

| Region (SA2 Name) | SA1 Code | Dominant demand pattern | IRSAD Score | PV Capacity (MW) | Battery Capacity (MWH) | 25 years NPV (Millions AUD) | LCOE (AUD/MWH) | Carbon emission reduction (t-CO2) |
|---|---|---|---|---|---|---|---|---|
| **Strathfieldsaye** | 2102401 | A | 1105 | 3.57 | 4.99 | 6.1850 | 98.37 | 673.28 |
| **Bendigo Region - South** | 2102614 | A | 1097 | 2.94 | 4.12 | 7.7284 | 81.38 | 731.33 |
| **Bendigo Region - South** | 2102616 | A | 1094 | 3.46 | 4.84 | 8.1010 | 90.87 | 718.64 |
| **Strathfieldsaye** | 2102410 | R | 1092 | 6.64 | 9.30 | 11.0733 | 63.74 | 149.47 |
| **Bendigo Region - South** | 2102603 | A | 1088 | 0.40 | 0.55 | 12.2569 | 78.75 | 87.82 |

(9) It is also recommended that Council consider advocacy for the development of medium to large-scale solar farm, which will have greater impact in offsetting electricity demand with renewable energy.

(10) In summary, the feasibility of the VPP potential deployment in Bendigo is time-sensitive and dependant of the capacity of PV and battery system. It is recommended that the priority be the ramping-up of the rooftop PV installation program along with the uptake of BESS systems before deploying a VPP system. **When the PV coverage reaches 25%-50% of the Bendigo's available rooftop, the VPP system will become an effective management strategy to further increase the value of renewable energy systems**. Reaching this level of coverage and beyond may require the use of new technologies such as building integrated PV (BIPV).

(11) Among all the communities, the industrial sector has the best net present value (NPV) performance, which is due to the high electricity consumption of the industry sector being greatly offset by the VPP. On the contrary, the residential sector has the poorest total NPV and average NPV.

(12) It is also recommended the City consider investigating opportunities to carry out small-scale pilot trails of the VPPs among the communities with greater socioeconomic advantages and

higher VPP economic potential. Table 3.5 identifies communities with higher socioeconomic index score as well as higher project net present value for implementing VPP in 10 years.

(13) In the longer term, Peer to Peer (P2P) trading can encourage energy self-sufficiency and consumption of locally generated renewable energy, enhancing local control and energy resilience, and facilitate energy goals of the City.

(14) The renewable energy transition comes with the requirements for technical and financial capability as well as community support and awareness.

(15) To advocate for funding and collaborations with the state and private sector, it is important that data is collected regularly so the opportunities and constraints with transition to a 100% local renewable energy system is identified in a timely manner.

The report recognises both VPP and community renewable energy P2P trading having significant ability to help the regional renewable transition goals.

VPP has benefits for the effective management of the existing renewable energy resources and for supporting the growth of renewable capacity in the future by enhancing economic value and carbon emission reduction performance.

P2P trading of renewable energy focuses on management support for high-demand users, it is also found that the proposed energy trading and management strategies' performance is depended on the capacity of local renewable energy.

**It is recommended that the initial priority for the City is to lead an increase in local renewable energy generation in the industrial and residential sectors.**

A knowledge-sharing platform has been created to improve regional communities' awareness of the opportunities to increase renewable generation within the Greater Bendigo area, and to provide valuable data for policy writers and decision makers at higher levels of government to understand how the transition could occur to promote future investment and decision-making.

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## Glossary of Terms / Abbreviations

Council: City of Greater Bendigo as an organisation

Greater Bendigo or the City: The broader Bendigo municipality as a community

DELWP: Department of Environment, Land, Water and Planning

ABS: Australian Bureau of Statistics

RCET: Renewable community energy transition

SA1: Statistical Area Level 1

POA: Postal Area

DSM: Digital surface model

BHM: Building height model

CHM: Canopy height model

DEM: Digital elevation model

VPP: Virtual power plant

PV: Photovoltaic

R-CNN: Region-based Convolutional Neural Networks

LCOE: Levelized cost of energy

PHSS:

High Energy User: what constitutes a high energy user like Coliban Water

BESS: Battery energy storage system

# 1. Introduction

The Greater Bendigo's Renewable Community Energy Transition (RCET) project was designed to: firstly understand the potential solar PV could play in transitioning the City towards 100% plus renewable energy and secondly, to outline a pathway for energy resilience and renewable capability through exploring the opportunities and challenges of community run energy generation and retail within the Greater Bendigo region.

Although the municipality is gifted with abundant solar resources, it still facing multiple technical and economic uncertainties such as the financial viability of renewable energy investment and the effectiveness of renewables in achieving the target of 500% of the region's 2021 energy demand is generated through locally generated renewable energy in Greater Bendigo by 2036.

Council has a great ambition to boost the uptake of the solar energy through home-owned distributed PV systems, and potentially community-scale PV solar farms. However, it is unclear how these systems can deliver the expected effects in demand offset, carbon reduction, and economic viability. In addition, most of the distributed PV and home battery systems have low visibility to the grid operator, which poses a challenge to the grid's stability and brings more uncertainties for future planning on the electricity supply infrastructure and the renewable energy transition roadmap.

The uptake of distributed and small-scale PV generators within Greater Bendigo is anticipated to grow fast with the Council proactively promoting renewable energy alternatives. There are also multiple streams of incentives, rebates, and support for solar PV systems by the State and Commonwealth Government, and opportunity for the further growth of the local renewable capacity.

The City needs to be proactive and take actions ahead of the anticipated demand growth and renewable energy growth to ensure community renewable energy is better situated in the decision-making process to achieve the 2036 renewable energy target for 500% of the region's 2021 energy demand is generated through locally generated renewable energy by 2036. The Council is interested in exploring the opportunities of a community-focused renewable energy solution to address the anticipated demand growth and renewable energy growth to potentially:

- Empower the community of Greater Bendigo to be energy self-reliant.
- Retain the value of Bendigo's energy system within the community.
- Accelerate economic transition to local renewable energy.
- Provide affordable and equitable power.
- Offer acceptable financial and energy security risk to the community.
- Increase local skills and employment opportunities.

This report supports a transition to a community-focused renewable energy transition. The feasibility studies for two types of renewable energy management strategies/business models (i.e., Community-based Virtual Power Plant and Community Level Renewable Energy P2P Trading) have been carried out. The studies evaluate renewable energy management strategies' impacts and benefits in terms of the energy performance, economic performance, and carbon emission reduction performance within the community.

## 1.1 Scope and objectives

The research project investigated the feasibility of introducing community energy generation and retail opportunities in a study area of Bendigo.

The performance of the proposed renewable energy management strategies is examined to consider the financial opportunities and risks. Data analysis is carried out for evaluating the decarbonisation, optimal management strategies and grid stability within the local communities with various supply-demand profiles, demographic conditions, and socioeconomic status.

The objective is to provide a better understanding of the challenges and opportunities of the renewable energy transition.

The objectives of this research project include:

1) Support decision-making on the further deployment of the Renewable Community Energy Transition (RCET)
2) Better identify the Council's role in the process of renewable energy transition
3) Identify the most suitable renewable energy solutions and management strategies to facilitate the achievement of the Council's renewable energy target
4) Identify opportunities to align with the Central Victorian Greenhouse Alliance (CVGA)'s Renewable Energy Roadmap

## 1.2 Tasks and milestones

The RCET project comprised four major Milestones:

1) Data collection and processing
2) Statistical Area 1 (SA1) level analysis
3) Urban level analysis
4) Community level analysis

Tasks performed to deliver the milestones were:

<u>Milestone 1: Collect and process data to create weather, supply & demand, and market data profile for the municipality by:</u>

1) Collection of Bendigo weather, electricity supply & demand and GIS data.
2) Preliminary analysis and data mining of collected data to establish Bendigo demand and generation profiles that can reflect close-to-reality conditions on SA1 level.
3) GIS based image recognition on Digital Surface Model (DSM) to identify potential area for PV.
4) Preliminary modelling.

<u>Milestone 2: Scenario modelling and assessment on SA1 level.</u>

1) Simulation of RCET operation on SA1 level.
2) Integrate multiple scenarios analysis of urban development, demand growth and renewable resources optional level changes.
3) Assess the performance of SA1 clusters through simulation and economic analysis.
4) Validate RCET strategies, scenarios, and preliminary results with key stakeholders.

<u>Milestone 3: Scenario modelling and assessment on urban level.</u>

1) Integrate the RCET framework with scenarios of urban-level generators.
2) Generate and assess the scenarios of future urban development.
3) Develop a web-based application to show the results.

Milestone 4: Community level.

1) Based on the analysis results of SA1 and urban level, define a community level user cluster
2) Create power management strategies for RCET simulation and conduct cost benefits analysis.
3) Validate results and findings through stakeholder interview and adjust RCET framework accordingly.

# 2. Methodology

## 2.1 Summary of research design and process

Based on a literature review conducted by the researchers previously [1], a research framework is designed to implement the RCET network and be refined according to local conditions (Figure 2.1). The research framework aims to address the stakeholders' expectations and concerns for distributed renewable energy management in the urban environment and to conduct analysis from SA1 level, urban level and community level.

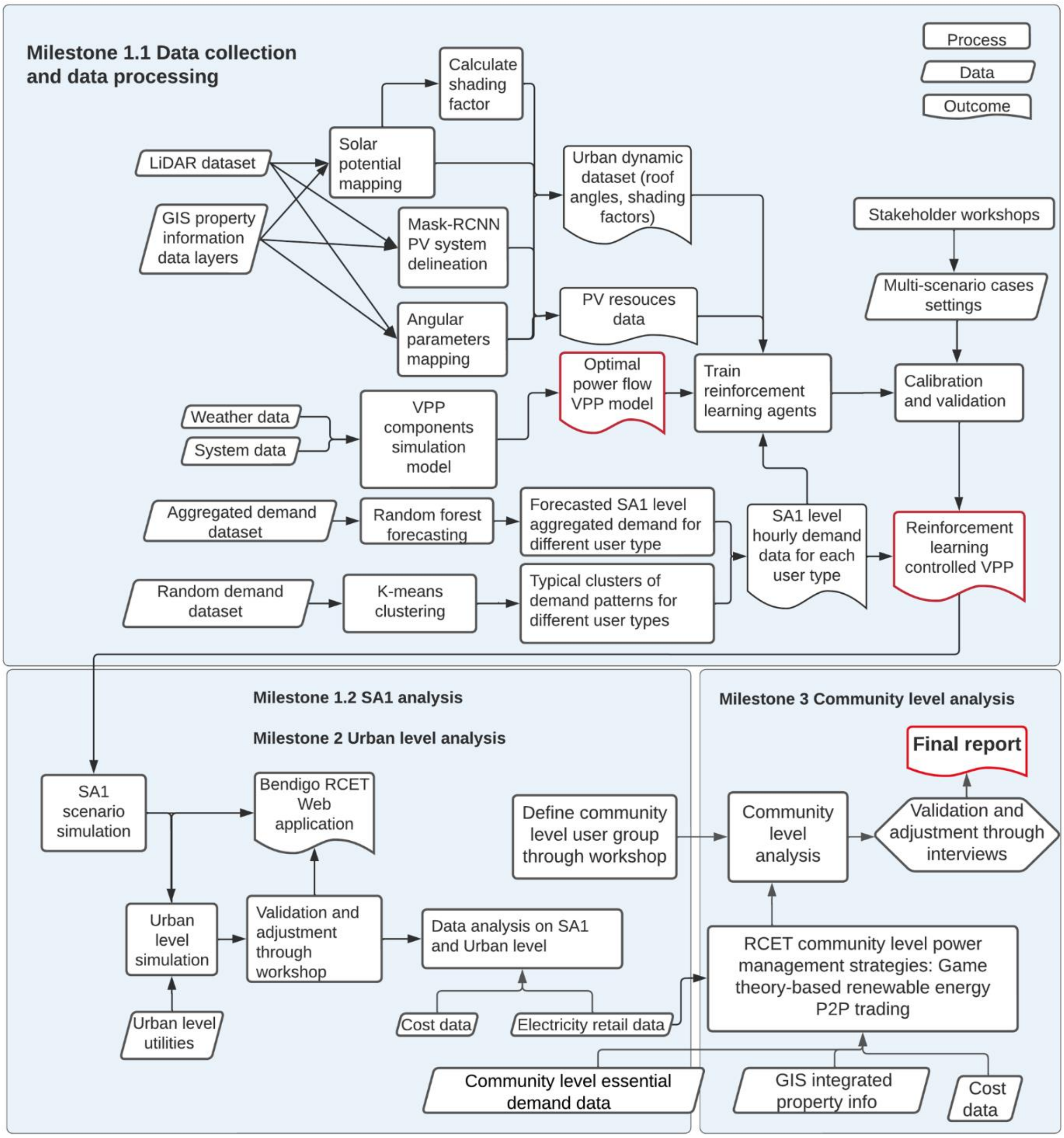


*Figure 2.1 Summary of the research process*

## 2.2 Summary of Methodology

To provide comprehensive analyses of the RCET framework with the local communities' urban environment conditions, supply-demand conditions, and socioeconomic and demographic profiles, this research employs a wide range of methods in achieving each task including data mining, GIS processing, reinforcement learning AI controlled VPP system, etc. following paragraphs will provide the explanation on the concepts and terminologies for an easy understanding of the research findings and observations.

### 2.2.1 Statistic Area Level 1 (SA1) as the community analysis unit

In this research, we adopt SA1 as the community unit for modelling and data analysis. The statistical area hierarchy (i.e.: SA1, SA2, SA3 and SA4) is introduced in Australian Statistical Geography Standard (ASGS) [2] to reflect the social geographic location of people and community. It is used for the publication and analysis of the ABS's statistics from censuses and other analysis. Among the statistical area hierarchy, SA1 is designed to maximise the geographic detail available for Census of Population and Housing data while maintaining confidentiality.

### 2.2.2 Study area and geospatial data coverage

This study covers a study area of 235 SA1s in the City of Greater Bendigo (Figure 2.2). The study area is limited by the LiDAR coverage area in the City of Greater Bendigo. The LiDAR data collected on March 2020 by the Department of Environment, Land, Water and Planning (DELWP) covers in total 235 SA1s of the City of Greater Bendigo. The LiDAR data was used to identify and measure the rooftop PV coverage, urban solar potential, building parameters and shading impacts.

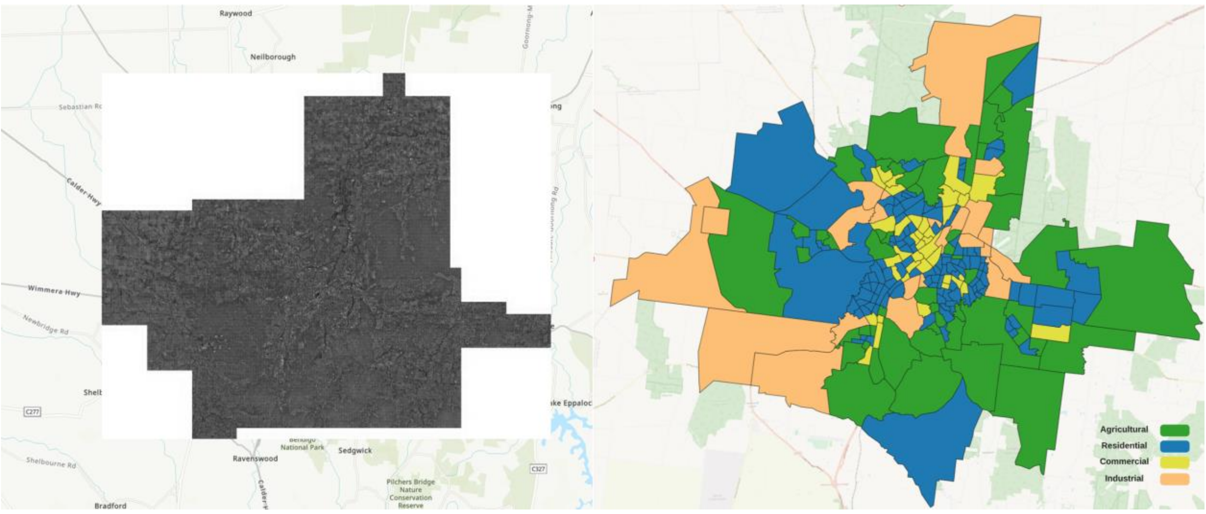


*Figure 2.3 LiDAR coverage in City of Greater Bendigo (Left) and the studied SA1s in this project (Right)*

### 2.2.3 Virtual Power Plant (VPP)

The virtual power plant (VPP) is an energy management system specially for distributed generators or small-scale generator. The VPP's concept utilises an energy network that aggregates small generators and demand to serve the functionalities of a normal generator including energy supply, network services, energy trading, etc. In the RCET project, the VPP is setup to operate within the SA1 communities as well as on the urban scale to provide optimal management for the PV and BESS in the region. In the data analysis part, the VPP's performance is assessed on both SA1 community level and the urban level.

In this project, a novel artificial intelligence (AI) approach call reinforcement learning (RL) was utilised to achieve the optimal control of the VPP and optimal scheduling of the distributed rooftop PV and battery energy storage systems (BESS). The RL controlled VPP system designed for RCET project is capable of adjusting electricity trading and scheduling strategies based on the observation and forecast of the users' demand, national energy market (NEM)'s electricity price for wholesale and FCAS services, and the renewable energy systems' output. Validation of the system capability is also carried out through statistical analysis and comparing to the benchmark system performance as provided by AEMO.

### 2.2.4 Community renewable P2P trading

The second renewable energy management strategy discussed in this report is the community-level P2P trading. The P2P trading allows the community members to bid and purchase electricity from each other. The potential outcomes of the P2P renewable energy trading include the increasing utilisation of the renewable capacity, reducing the impact of exporting distributed generator's output to the grid, increasing the economic value of the renewable generator investment. In this project, we adopt several game-theory based trading algorithms to investigate the economic and energy potential of this trading mechanism.

### 2.2.5 Scenario settings

The multiple scenario analysis of this study will investigate the impacts of different RCET operation strategies under the different scenario cases. When generating scenario cases, this research considers the spatial and temporal dynamics of the urban environment in terms of the demand/supply changes, market changes, etc. These changes are developed into multiple scenario cases that will be simulated and analysed using the VPP model. When generating scenario cases, the following aspects are considered:

A. Potential deployment of PV panels in the future.
B. Energy storage devices and facilities (i.e. home battery systems and large-scale storage systems).
C. Electricity demand growth

***Scenario group A: Scenarios of potential PV coverage***

Based on the PV system delieanation results, the PV coverage scenario was established considering solar potential, rooftop orientation, the slope of the roof and the rooftops' financial viability for deploying PV systems. The scenarios included (1) Base case with currently detected solar panels, (2) Medium coverage ratio scenario (25% of total available rooftop), (3) High coverage ratio scenario (50% of total available rooftop).

***Scenario group B: Scenarios of electricity storage facilities***

The PV-battery ratio is an essential factor to be considered when designing a distributed PV system. Many studies have investigated the coverage ratio impact of PV system and battery system on self-sufficiency capability and economic performance [3-6]. However, most of these studies applied scenario analysis that investigate different ratios' performance. The recommended ratio ranges from 50% to 200% as can be found in these studies. Based on a recommended system ratio from an Australian State Government document, the baseline ratio in this research is set for 70% of the PV system capacity [7]. For scenario group B, three cases are introduced: (1) base case scenario without battery capacity, which affects the base case VPP operation scenario only, (2) battery capacity of 70% PV capacity, (3) battery capacity of 140% PV capacity and (4) battery capacity with 210% PV capacity.

***Scenario group C: Scenarios for electricity demand growth***

The demand growth scenario has three scenario cases: (1) Current demand, (2) 5 years demand growth, and (3) 10 years demand growth. Among the three scenario cases, the current demand is based on the demand data as introduced in Section 5.3. The cases 2 and 3 are the amplified demand using the estimated demand growth rate recommended by Australian Department of Industry, Science, Energy and Resources (DISER) [8]. In the DISER's 2020 report, the recent growth rate for 2019-2020 is used to estimate the five years growth in the near future, while the DISER's estimated 10 years growth rate is used for the long-term demand growth.

*Table 2.1 Demand growth rate for short term (5 years) and long term (10 years) [8]*

| User sector | 5-years annual growth rate (%) | 10-years annual growth rate (%) |
|---|---|---|
| Residential | 2.7 | 0.5 |
| Commercial | 1.1 | 1.8 |
| Agriculture | -1.0 | 0.8 |

| | | |
|---|---|---|
| **Industrial/Manufacturing** | -1.9 | -2.0 |

# 3. Findings, observations and research outputs

## 3.1 Rooftop solar PV resources in Greater Bendigo: Present and Future

Through the solar potential mapping process, the RCET project delineates the installed rooftop PV system covered by the subject area and conducts mapping of the rooftop PV potential, based on DELWP's aerial image data in May 2020. It is found that the existing installed PV in the subject area has a total estimated capacity of around 50 MW which covers the rooftop area of around 298,000 $m^2$. The current rooftop installation already has an effect in the electricity demand offset, creating a 4.43% in the annual electricity demand (Figure 3.1). The majority of the current rooftop PV contribution in the subject area is from residential communities.

*Table 3.1 Percentage of the properties that have PV installed*

| | Residential property | Agricultural property | Industrial property | Commercial property | Average |
|---|---|---|---|---|---|
| **% of properties that have rooftop PV installed** | 47.05% | 13.62% | 21.94% | 29.15% | 27.94% |

The Table 3.2 presents the percentage of properties in the subject area that have existing PV installed. It is identified that residential land has a much higher percentage than the other land uses and that nearly half of the residential properties have installed PV systems in the study area.

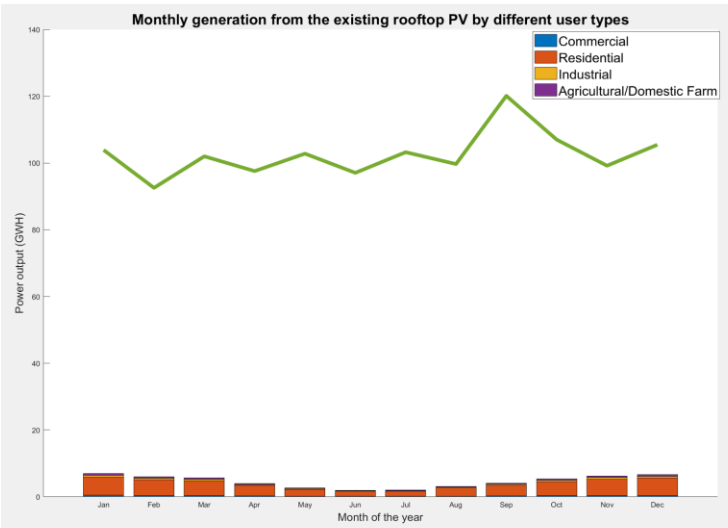


*Figure 3.2 Monthly simulated PV generation from existing rooftop PV in comparison with the monthly demand*

To have a significant improvement in the demand offset before 2036, the simulation concludes that an annual rooftop PV growth rate of around 5%. The current rooftop PV coverage growth percentage is around 1.73%. At a 5% growth rate (132.5 MW/year or 662,500 $m^2$/year), the rooftop PV coverage will reach medium PV coverage scenario (25% of the total rooftop area PV coverage – equivalent capacity: 752 MW) in 5 years, which will cover around 4,396,605 $m^2$ of the rooftop and have a total generation of 718.50 GWH.

In 10 years, the rooftop PV will cover a rooftop area of 8,793,210 $m^2$ (50% rooftop PV coverage - equivalent capacity: 1.54 GW) and produce 1,437 GWH electricity per year.

Although in both 25% and 50% rooftop coverage scenarios, the rooftop PV can generate a mass amount of electricity over the year, due to the unmatched demand and PV output, the demand offset ratios for these scenarios are 35.27% and 40.52% respectively. Operating a large amount of PV without storage system or energy management system mean that a large amount of electricity output from PV will be exported to the grid.

To further improve the rooftop PV's utilisation and efficiency in the future, there is the need for a storage capacity of around 526.4 MWH (70% of the PV installed capacity – Low BESS scenario) when the rooftop PV coverage reaches 25%, so that the PV output can be effectively tuned to cover the demand after sunset. To achieve the 526.6 MWH storage capacity with distributed battery storage systems, using an example of the popular home BESS product TESLA Powerwall which has a usable capacity of over 10 kWh per unit. The annual growth rate of 105.3 MWH results in around 7,800 BESS units need to be installed each year, which is equivalent to less than two in ten households getting a battery each year.

If the BESS capacity supporting rooftop PV could reach low-capacity scenario (70% of the PV capacity) in 5 years with a total storage capacity of 526.4 MWH, the monthly demand offset will have a pattern as shown in Figure 3.3. The total estimated annual electricity demand offset with this scenario will reach 48.36%. In the scenario with 50% PV coverage scenario, the demand offset will be 67.98% (Figure 3.4).

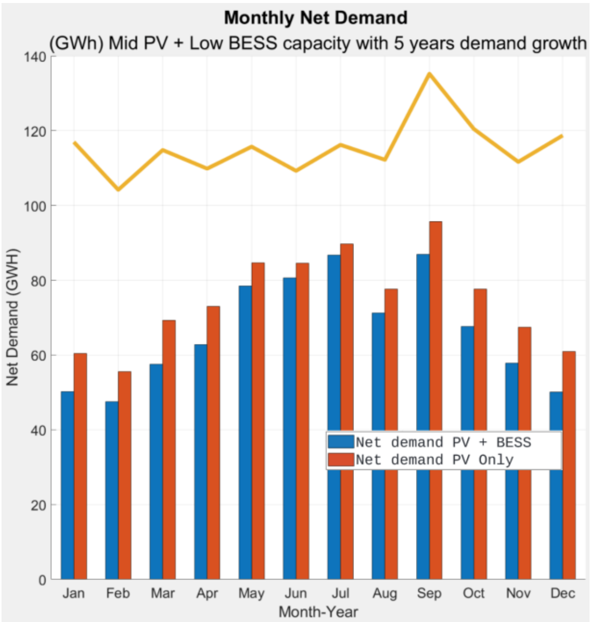


*Figure 3.3 CoGB's projected net electricity demand in 5 years with 5% rooftop PV annual growth*

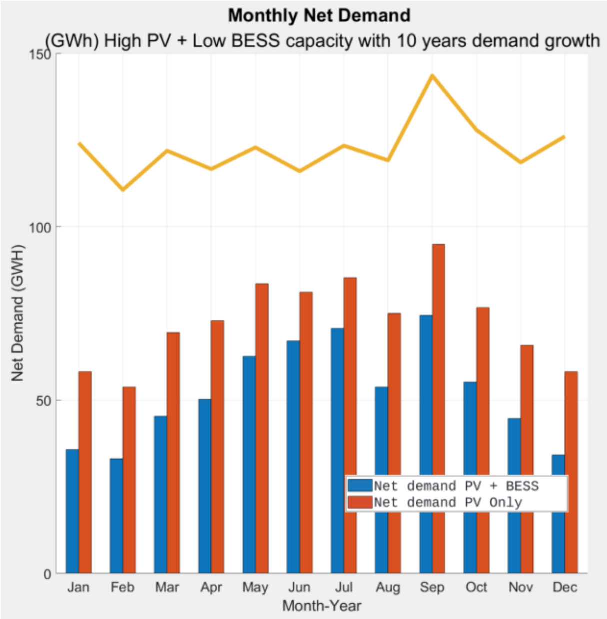


*Figure 3.4 CoGB's projected net electricity demand in 10 years with 5% rooftop PV annual growth*

Using rooftop PV and home BESS alone cannot meet 100% locally generated renewable energy. The maximum demand offset ratio by utilising all available rooftop is around 80%. Therefore, in addition to the rooftop PV and home BESS systems, the scenario analysis also needs to evaluate the potential development of a large-scale solar farm and energy storage system (ESS) such as pumped hydro storage system. Figure 3.5 shows two scenarios that can facilitate the 100% local renewable energy in 5 years and 10 years. In the 5-year growth scenario, the VPP requires large-scale solar and pumped-hydro storage system (PHSS) with capacities of 600 MW and 1.2 GWH respectively. With an additional 300 MW PV farm and a 630 MWH ESS system, it is possible to greatly offset the demand considering the 10 year's demand growth rate.

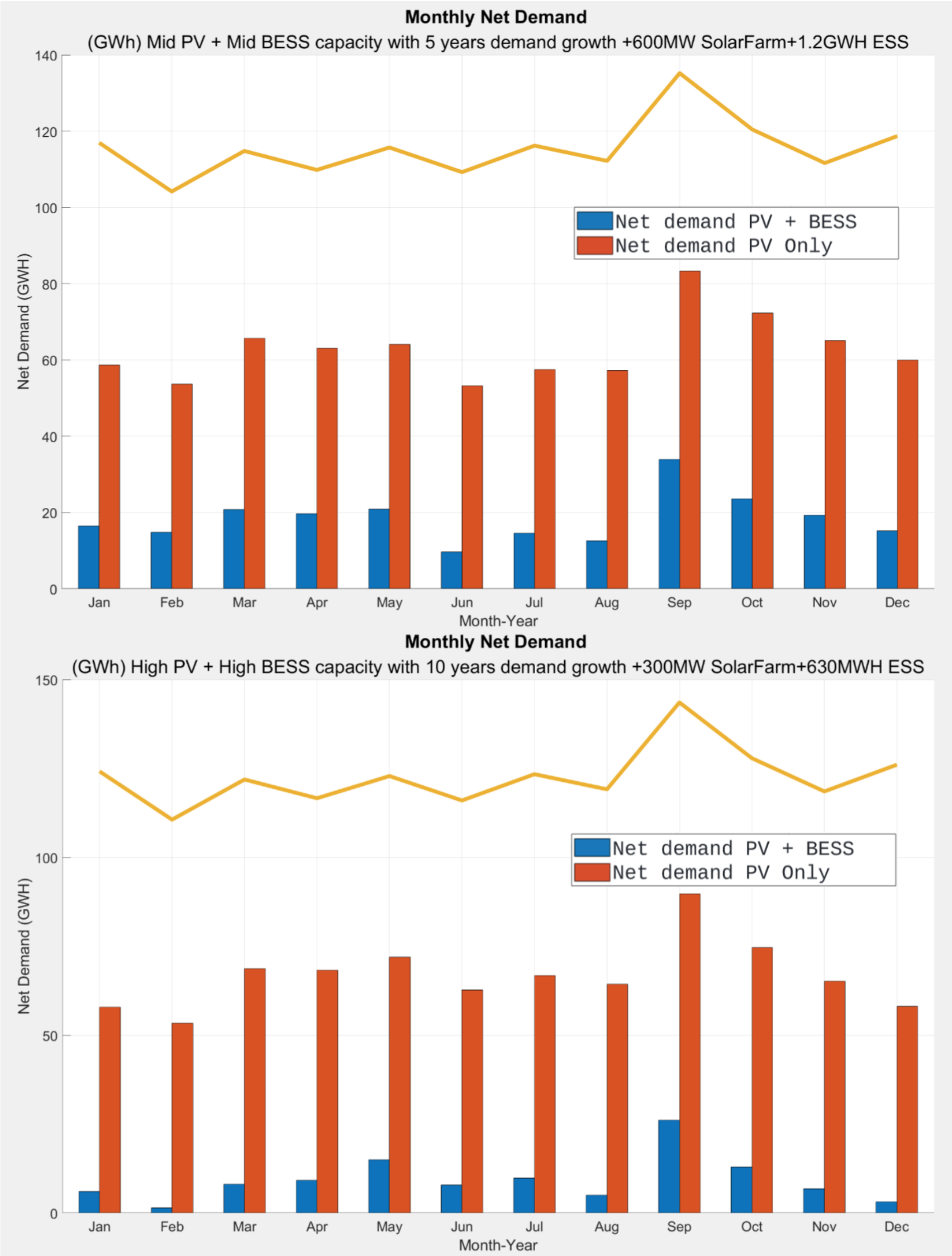


*Figure 3.5 Monthly net demand of Mid-High PV coverage scenarios with utility size PV and ESS*

In summary, observations and findings regarding the PV resources for future development, there is great solar potential for PV resources to significantly offset the study area's electricity demand. The study area needs to have a rapid growth in both rooftop PV and BESS systems with an estimated growth rate of 132.5 MW/year (Less than 662,500 $m^2$/year for PV module with efficiency higher than 20%) for rooftop PV and around 7,800 units/year for BESS (unit capacity of 13.5 kWh). With this rate, it is expected to achieve demand offset of 48.36% in 5 years and 67.98% in 10 years. It is also recommended considering the further development of a medium to large-scale solar farm and the potential utilisation of the underground pump-hydro storage system (PHSS)[2], which will have greater impact in offsetting electricity demand with renewable energy.

## 3.2 VPP feasibility study

This section discusses the feasibility of a distributed renewable energy management system – VPP from the following aspects:

1) Carbon emission reduction.
2) Gird impacts measured by load factor.
3) Project financial viability measured by net present value (NPV).
4) Effects in reducing electricity costs.
5) Electricity generation cost measured by levelized cost of energy (LCOE).

The key findings and observations of the VPP feasibility study are detailed.

### 3.2.1 Carbon emission reduction

Table 3.3 summarises the carbon emission reduction performance with and without battery systems. The battery systems reduce carbon emissions more effectively than the business-as-usual scenario.

*Table 3.4 Estimated carbon emission reduction at present and in the future with the suggested PV & BESS growth rates*

| | Total carbon emission (Kilo tons) | Carbon emission reduction without battery (Kilo tons) | Carbon emission reduction with battery (Kilo tons) |
|---|---|---|---|
| **Current** | 1,206.0 | 53.4 – 4.4 % | 56.8 – 4.8% |
| **5 years** | 1,357.4 | 478.8 – 35.3% | 656.49 – 48.4% |
| **10 years** | 1,441.3 | 584.04 – 40.5% | 461.55 – 68.0% |

### 3.2.2 Grid impacts measured by load factor

Load factor is a measurement of an electricity network's efficiency and stability. When a low load factor is reported, the electricity supply grid is running at a low efficiency, and if the energy network has a high load factor, it indicates that the network is operating at its designed capacity. The data analysis identified the VPP system has negative impacts on the load factor within SA1 communities at current PV coverage level. The reason is that PV has higher output during the daytime while the users are not experiencing their peak demand. However, the PV output is not high enough to last in the system until the peak demand, therefor the VPP system increases the deviation of the off-peak demand and peak-demand, which reduces the grid efficiency.

The load factor is improved as the PV and BESS systems capacity grows. In the 5 years scenario, the load factors among SA1 communities have a similar pattern as the current load factors with less than 25% of the SA1s having low load factors below 60%. While in the 10 years scenario, the VPPs show the effects in improving grid stability and consumption efficiency that more SA1s are reported to have higher load factors compared to the current values.

[2] Based on the Pre-feasibility study report of renewable energy pumped hydro in Bendigo prepared by ARUP for DELWP and City of Greater Bendigo. Year 2018. The pre-feasibility study provided the conceptual design of the underground hydro pump storage system utilising Bendigo's old mine shafts, which can provide over 180 MWH storage capacity with maximum hourly charge/discharge power of 30 MW for over 6 hours.

### 3.2.3 Project financial viability measured by NPV

It is identified the financial performance of VPP largely relies on the capacity of renewable generators and storage systems. If the capacity remains at current level, the forecasted net present value (NPV) for investing in community-level VPP will be low. The simulation results on the 25 years project NPV indicates that with current PV coverage, most of SA1s have low NPV or negative NPV values and the lowest NPV is found at around -5 to -4 million AUD. Current scenarios suggest around 34-35% SA1s have positive NPV values. This indicates that the investment on VPP with current installed PV capacity is not a financial viable option due a relatively low expected payback.

When the PV coverage increases to medium or high level, the NPV among SA1s shows a pattern of increasing, with over 88% of the SA1s populated above 1 million AUD in the 5 years scenario. The percentage grows up to above 90% of the SA1s have higher NPV than 1 million AUD in the 10 years scenario.

Although increasing PV capacity will have a positive impact on the VPP's NPV among the SA1s, the increase in BESS capacity can have a double-sided effect on the project NPV. For example, if an SA1 community already has a higher estimated profit (above 10 million AUD 25 years NPV), extra BESS capacity will be more likely to further increase the profits level. On the contrary, if an SA1 community has a estimated profit less than 1 million AUD, the extra BESS capacity that incur more initial cost and maintenance cost will have higher chance to reduce the exiting profit.

In summary, the economic payback and project value of the future VPP deployment largely rely on the capacity of PV and BESS system. Higher PV and BESS system capacity gives VPP greater capability in demand offset and energy trading. It can also be found that the high BESS capacity can sometimes reduce project economic feasibility, which may be due to the high capital cost and maintenance cost of the BESS system. Among all the SA1 communities, the industrial sector has the best NPV performance, which is due to that the high electricity consumption of the industry sector greatly offset by the VPP. On the contrary, the residential sector has the poorest total NPV and average NPV.

### 3.2.4 Effects in reducing electricity costs

VPP's economic performance has strong impact on reducing the electricity cost for the local communities, even with the current PV installation capacity. Most of the SA1s with current PV capacity and low BESS capacity have reduced electricity price ranging from 0.05 to 0.08 AUD/kWh while over 50% of the SA1s have the electricity price of less than 0.01 AUD. This illustrates a significant reduction compared to the Default Offer electricity price (ranging from 0.1297 to 0.3091 AUD/kWh excluding the service charge) provided by the Essential Services Commission (ESC) of Victoria [9]. This demonstrates that the VPP has significant capacity in reducing the users' electricity expenditure with different demand profiles.

### 3.2.5 Electricity generation cost measured by levelized cost of energy (LCOE)

The LCOE is a measurement of the cost for generating electricity. It is found that the VPPs' LCOE remains at a very high level (above AUD 1000/MWH) at current PV coverage scenario. The LCOE of VPPs in SA1 communities see a significant improvement with increasing PV and BESS capacity with 90% of the SA1 has LCOE ranges from AUD 60-160 per MWH in the 5 years scenario, and 90% SA1s' LCOE ranges from AUD 70-130 per MWH in the 10 years scenarios. In both scenarios, the VPPs have lower generation costs compared to fossil fuel generators of natural gas and coals which ranges from AUD $100-350/MWH [10].

### 3.2.6 Summary of VPP feasibility study and recommendation for future development

Among the five factors listed above, the analysis shows that VPP's have poor performance in terms of carbon emission reduction, load factor, net present value and levelized cost of energy when considering the current PV capacity and the BESS capacity is low. One exception is the adjusted electricity price, which is much lower than the Default Offer price even at a low PV coverage level. The VPP's performance in all five factors sees great improvement in the 5–10-year timeframe given that PV and BESS systems if the recommended growth rate of 132.5 MW/year for rooftop PV and around 7,800 units/year for BESS is achieved.

The feasibility of the VPP potential deployment in the Greater Bendigo region is time-sensitive and dependant of the capacity of PV and BESS system. Based on the findings, it is recommended the City prioritise the ramping-up the rooftop PV installation along with the uptake of BESS systems before deploying a VPP system in the municipality. When the PV coverage reaches 25%-50% of the municipality's available rooftop, the VPP system will become an effective management strategy to further increase the value of renewable energy systems.

It is recommended to carry out small-scale pilot trails of the VPPs among the communities with greater socioeconomic advantages and higher VPP economic potential. Table 3.5 below shows the identified SA1 communities with higher socioeconomic index score as well as higher project net present value for implementing VPP in 10 years.

*Table 3.5 Suggested SA1 communities for pilot implementation of VPP*

| Region | SA1 Code | IER rank | IEO rank | IRSAD rank | IRSAD Score | PV coverage percentage | 25 years NPV (Millions AUD) | LCOE (AUD/MWH) | Carbon emission reduction (t-CO2) |
|---|---|---|---|---|---|---|---|---|---|
| Strathfieldsaye | 2102401 | 10 | 8 | 9 | 1105 | 2.24% | 6.1850 | 98.37 | 673.28 |
| Bendigo Region - South | 2102614 | 10 | 8 | 9 | 1097 | 1.89% | 7.7284 | 81.38 | 731.33 |
| Bendigo Region - South | 2102616 | 9 | 9 | 9 | 1094 | 2.03% | 8.1010 | 90.87 | 718.64 |
| Strathfieldsaye | 2102410 | 10 | 7 | 9 | 1092 | 2.90% | 11.0733 | 63.74 | 149.47 |
| Bendigo Region - South | 2102603 | 10 | 8 | 9 | 1088 | 1.52% | 12.2569 | 78.75 | 87.82 |

## 3.3 Community-level P2P trading feasibility study

In comparison with VPP, which provide energy management services on entire community, the P2P trading solution proposed in RCET project is tailored for high demand users that account for higher electricity consumption and carbon emission. The P2P trading system provides an alternative for these users to directly utilise the renewable resources in the surrounding neighbourhoods. With the aid of the embedded game-theory auction algorithm, this solution not only provides the opportunity to manage the high demand locally, but it is also able to unlock the potential value of the prosumer-owned PV and BESS.

Based on the community level analysis, this study identified one of the high demand users. Simulations for multiple game-theory based P2P trading were then carried out to evaluate economic and energy performance. It is found that adopting P2P trading at the community level can comparatively reduce the energy bills for the identified high demand user, reduces non-renewable energy dependency from the national grid and increase return for the household prosumers. The game-theory based auction also has an effect in motivating the prosumers to actively participate in the bidding process, which increases the value generation of the distributed PV system as well as reducing the high demand user's reliance on the non-renewable energy.

Due to the limited research scope and timeframe, this study does not perform a comprehensive analysis on the P2P trading performance in its whole dimension. However, in a longer term, P2P trading can encourage energy self-sufficiency and local consumption of locally generated renewable energy, enhance local control and energy resilience, and facilitate energy goals of Council.

## 3.4 Knowledge-sharing web platform of the RCET project

Carried out was a detailed analysis on renewable energy management strategies to support the City's renewable transition target. As previous discussed, strategic management of the renewable resources has the potential to benefit the Victorian Government departments in terms of advising the future growth of renewable energy capacity and the feasible renewable energy strategies. There is however still a long journey ahead to bring the concepts into practice, which requires broader public awareness as well as investment interests.

To raise the awareness of the renewable transition a web application tool was developed integrating the research data, analysis tools and visualised results with free access to the public. The main purpose is to increase the visibility of this research in the community as well as the stakeholders such as policymakers and potential investors. It also increases the transparency of the data analysis conducted by researchers since the process is repeatable for the potential users of the website. The web application is built using the Amazon Web Services (AWS) infrastructure. A relatively user-friendly interface is designed to navigate the users of the web application through the functions. Major research data are stored in the AWS web database which can be used by the users to perform data analysis and visualisation of the results.

The data and results shown in the Bendigo's RCET web application (BRCET) include the following:

1) The visualised GIS results including PV system delineation and PV potential mapping in greater Bendigo urban area.
2) SA1 level simulation results of all scenario settings.
3) Urban level simulation results of all scenario settings.
4) A built-in PV/ESS simulation tool that can visualise user defined PV/ESS system output.
5) Socioeconomic analysis visualisation layers.

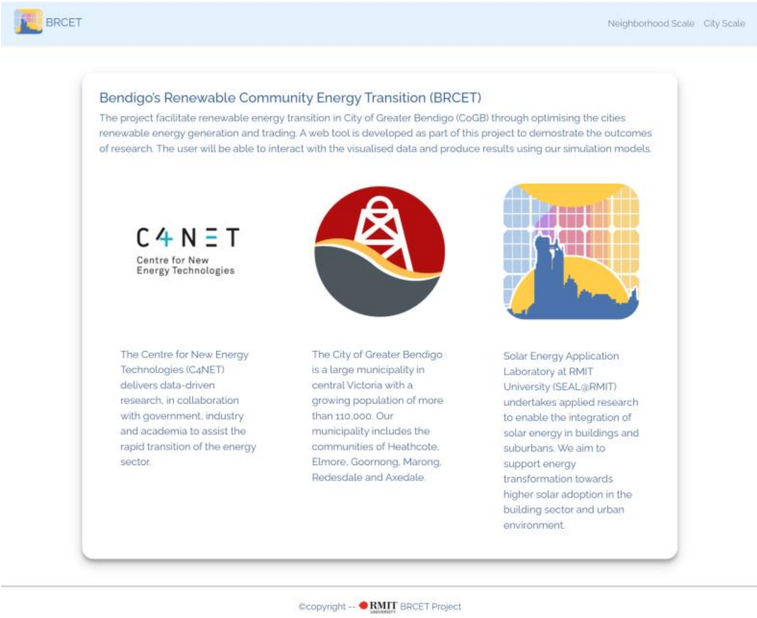


*Figure 3.6 Home page of the BRCET*

In the home page (Figure 3.6), the user can select either neighbourhood scale (SA1) analysis or city scale analysis to access the SA1 level results or the urban level results. When accessing SA1 level results, the user may select the SA1 by directly clicking on the map or conducting an address search using the embedded map search function.

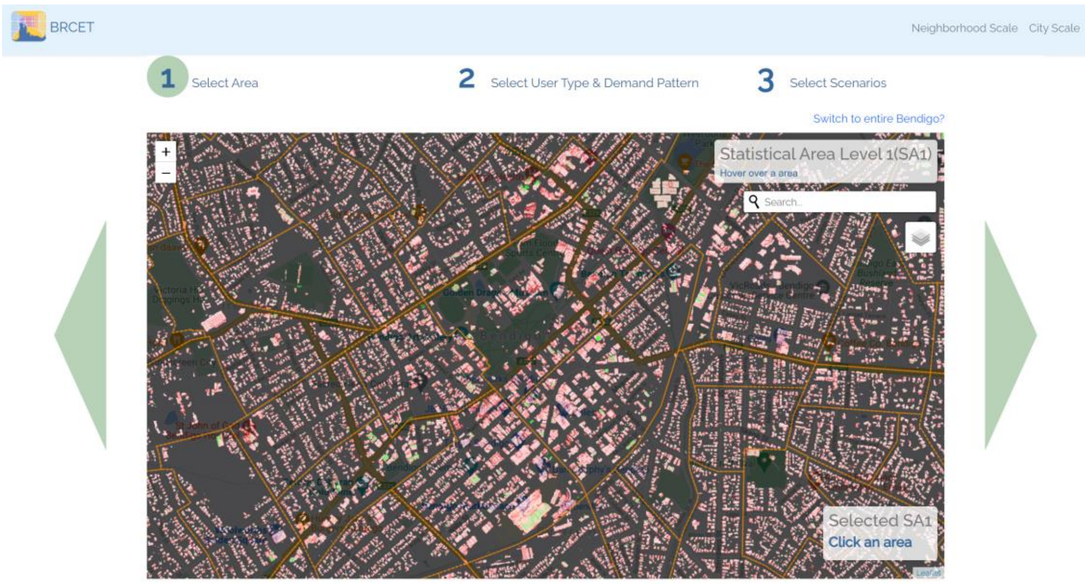


*Figure 3.7 PV delineation and solar potential mapping visualisation in the web application*

Following the SA1 selection and visualisation, the user is asked to select the demand data types including the demand user sector (Agricultural/Domestic farm, Commercial, Industrial, Residential, or aggregated total demand) and the seasonal demand patterns. Then, the user is asked to select scenarios for accessing the results. The scenario setting page (Figure 3.8) reflects the scenario cases for the data analysis. Slight modifications are made to the available options. For example, the BESS option has only two options which are 'BESS exist' or 'BESS does not exist'. The purpose is to reduce some scenario options so that the database will have a reduced size. Also, detailed descriptions are added to the scenario options as popup dialogs to facilitate the user to better understand each option.

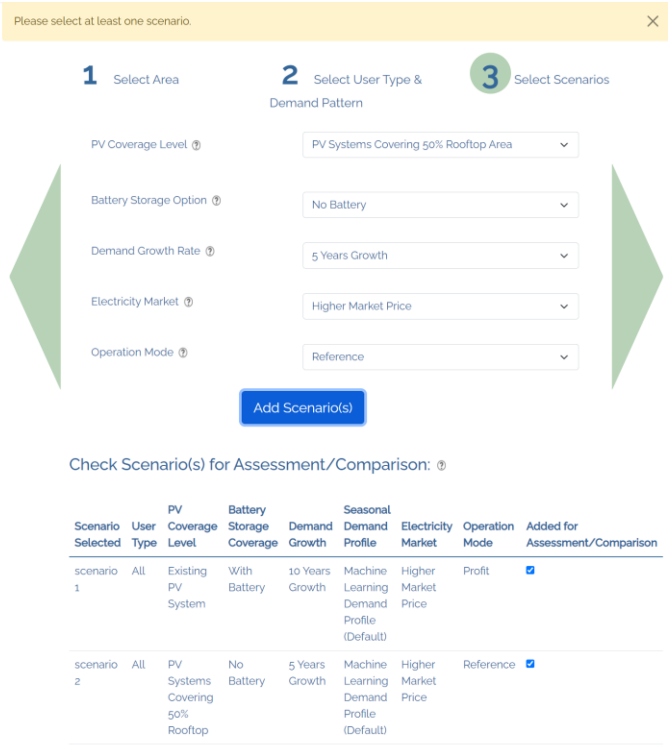


*Figure 3.9 Scenario setting page*

The scenario setting page supports the selection of more than one scenario cases for comparison. The user can also navigate among the three steps to change the SA1, demand data or the scenario cases. When the scenario cases are determined, the user may proceed to generate the results (Figure 3.10).


*Figure 3.11 Generated results based on the scenario selection*

As shown in Figure 3.12, the information of the selected SA1 is displayed. This information includes the user selected scenario cases, the SA1 demographic profiles, the SA1 PV installation condition, and the summary economic and environmental performance of the selected scenarios.

The demographic profile includes population number, gender distribution, household number, household income, etc. The demographic profile is obtained from the ABS based on the recent census data in 2016.

The economic and environmental performance of the scenario shows the calculated results of total cashflow, incomes from providing FCAS services and the CO2 emission reductions. The cashflow calculation include the expenditures on electricity imported, profits from exporting and profits from FCAS services. The CO2 emission reduction is calculated based on the National Greenhouse Account Factors 2020 by the DISER [11]. It should also be noted that the FCAS income will only be considered when the BESS option is 'BESS exist'.

The results from each scenario are visualised and displayed in monthly bar chart as shown in Figure 7.4.4. The displayed results include the monthly PV generation, electricity demand and the monthly grid exchanged power. Visualising the data allows the user to easily compare different scenarios in various settings.

In addition to the SA1 level results, the web application also provides access to the urban level results. The urban level results are the aggregation of SA1 level results of different scenarios. Furthermore, the user is able to define extra solar farms or large-scale ESS in the scenario setting pages. The definable parameters include PV system's tilt angle, azimuth angle, reference efficiency, system capacity, BESS's capacity, efficiency, and maximum charge/discharge power (Figure 3.13). Except for the results shown in Figure 3.9.4, the urban level result also includes the adjusted monthly grid exchange and PV output under the effects of the user defined utilities.

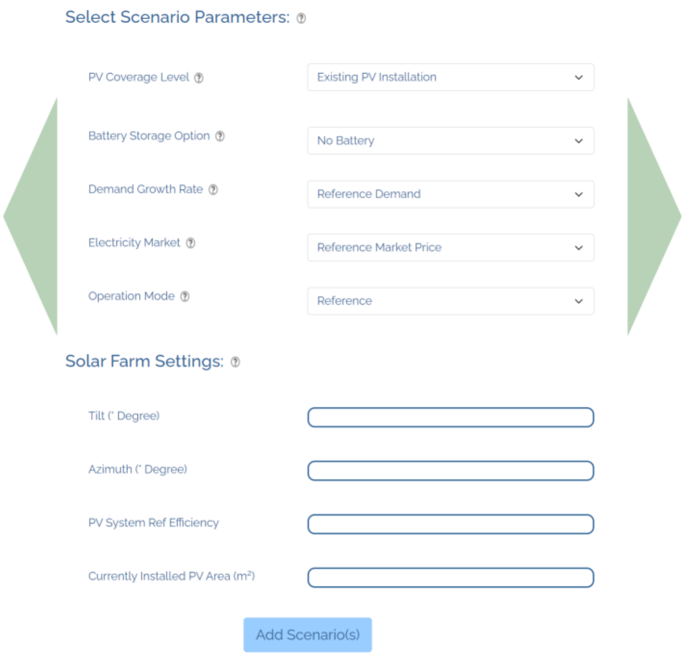


*Figure 3.14 Scenario setting for urban level results*

In addition to the above-mentioned functionalities, the BRCET web tool also provides the analysis results of socioeconomic factors overlaying with the VPP's simulation results (Figure 3.15). These layers include the overlaying of the two categories of data (1) Socioeconomic factors: SEIFA indices (economic resource, education, employment, overall advantages and disadvantages) and dwelling types; and (2) Renewable energy performance data: annual grid exchange, PV coverage and 25 years NPV. These visualisation layers aim to provide the users with a straightforward presentation of the SA1 communities renewable energy performance and their socioeconomic conditions, which could benefit the future investment and policy-making of the renewable energy development.

The socioeconomic factors selected are the Index of Relative Socio-economic Advantage and Disadvantage (IRSAD); The Index of Education and Occupation (IEO); the Index of Economic Resources (IER); and the SA1 level dwelling types. The data used for socioeconomic analysis is the SEIFA indices produced by ABS based on the 2016 Census data.

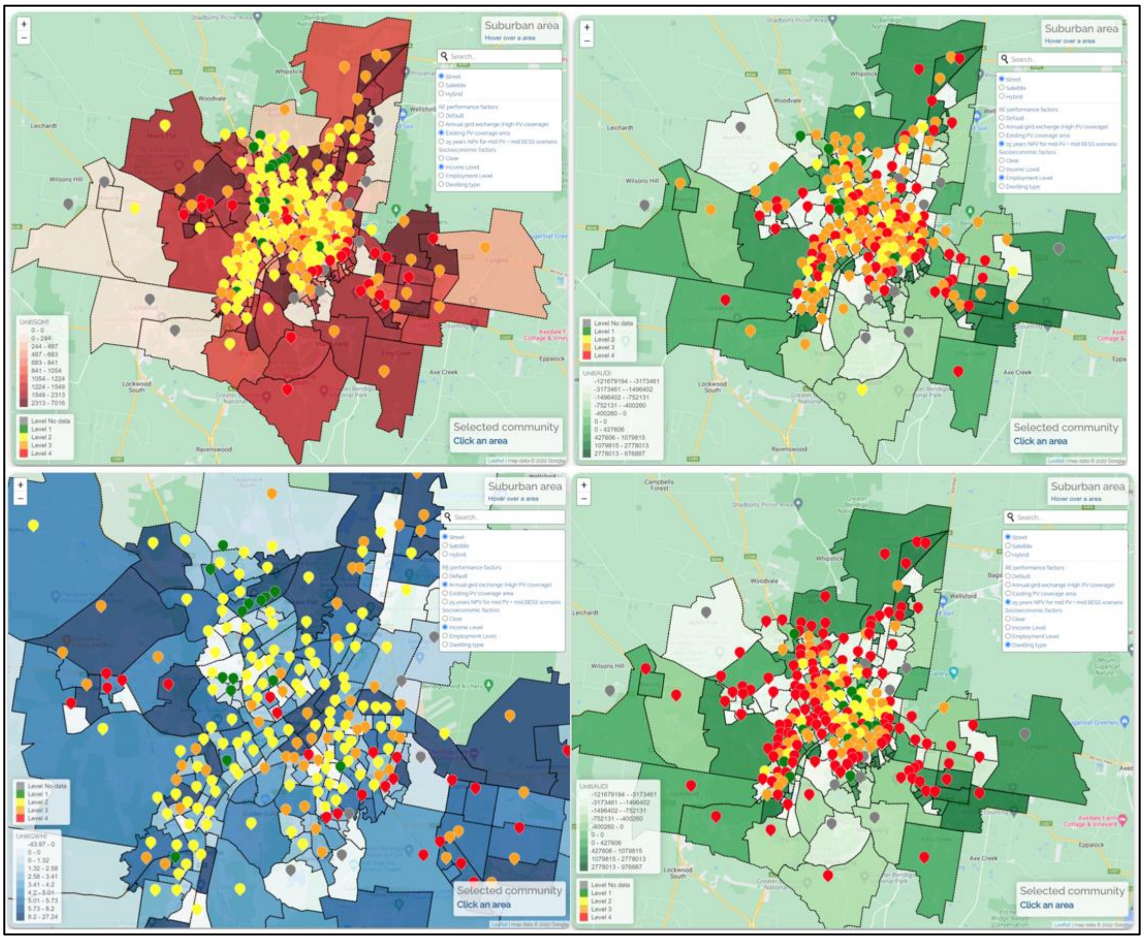


*Figure 3.16 Sample visualisation layers on BRCET web tool (https://www.sealsolarlab.com/overall)*

# 4. Conclusions

The RCET project carried out a detailed study on the renewable energy management strategies with the potential to support the City in achieving its 2036 energy target.

The key findings and recommendations for future development of VPP are summarised as the followings:

## 4.1 Key findings

- The City of Greater Bendigo has great solar potential for PV resources which could be utilised to significantly offset the City's electricity demand.

- The current PV coverage rate is the study area of this project is 1.73% of the total rooftop area. Around 27.94% of properties in the study area have installed PV systems.

- The VPP have greater benefits in improving the economic and environmental values of the rooftop PV and community battery systems in the Greater Bendigo area, especially with higher PV coverage and battery capacity.

- However, at current PV coverage level, the implementation of VPP is not a feasible option due to the negative project economic value, higher levelized cost of energy, and relatively poor performance in demand offset and carbon emission reduction. Nevertheless, analysis on the 5 years and 10 years scenarios proves that the VPP has great potential to support the City's future growth of renewable energy system and unlock the distributed system's values among the communities.

- Bendigo's solar PV potential could substantially provide the community's electricity needs in the near future. **To do this, Bendigo needs significant expansion in rooftop PV and battery systems, with 132.5 MW/year for rooftop PV and 7,800 units/year for BESS (unit capacity of 13.5 kWh). At this rate, the community will offset demand by 48.36% in 5 years and 67.98% in 10 years.**

- To achieve a significant renewable energy transition, the priority for Bendigo is to fast track the installation of solar PV and home/community battery system capacity. Ideally, a PV growth rate of 132.5 MW/year (Current total installed capacity: 93 MW) will achieve the 50% - 70% carbon emission reduction for the municipality in 10 years' time. With an example of a PV unit that has 2m2 size or 400-Watt DC capacity, this growth rate is equivalent to 331 thousand units per year.

- For battery systems, the ideal growth rate is around 7,800 units/year. Using the TESLA Powerwall battery system as an example with  usable capacity of over 10 kWh/unit, this growth rate equivalent to around two in ten households installing a battery unit per year.

- With the 132.5 MW/year ideal growth rate, in 10 years, the rooftop PV will cover a rooftop area of 8,793,210 m2 (50% rooftop PV coverage - equivalent capacity: 1.54 GWH) and produce 1,437 GWH electricity per year. Although in both 25% and 50% rooftop coverage scenarios, the rooftop PV can generate a mass amount of electricity over the year, due to the unmatched demand and PV output, the demand offset ratios for these scenarios are 35.27% and 40.52% respectively.

- The VPP have greater benefits in improving the load factor in SA1s when PV coverage level is higher. When PV coverage level reaches 50% of the rooftop 85% of the SA1s have higher electricity network efficiency compared to the scenario without VPP model's control.

- Ideally, with an increase in PV coverage to 25% of the rooftop coverage, over 50% of the SA1 communities will have a significant reduction in the carbon emission. When the PV coverage further increase to 50% of the rooftop, over 70% of the SA1 communities will reduce the carbon emission by half.

- Home battery systems have the effect in maintaining the carbon emission reduction against the demand growth. Compared with the scenario groups with low home battery systems capacity, those with mid to high home battery systems capacity will remain a higher carbon emission reduction rate even as the electricity consumption continues to grow at a high growth rate.

- On average, communities with an industrial dominated electricity consumption pattern have the best outcomes in carbon emission reduction rate, followed by the commercial sector, while the residential sector has the lowest effects. The explanation is related to their demand patterns, PV output can be greatly utilised by the industrial and commercial users because they have higher daytime consumption.

- The industrial demand pattern dominated SA1s have the best net present value (NPV) performance among all sectors due to the significant amount of electricity consumption offset by the VPP.

- Residential demand pattern dominated SA1s have lowest net present value (NPV) due to the reason that the residential sector usually has its peak demand after sunset, which limits the VPP's capacity in demand offset.

- A VPP has great capability in reducing the user's expenditure on electricity in all the scenarios when the adjusted electricity price lower than the Default Offer as provided by the Victoria Essential Service Commission.

- With 25%-50% PV coverage, the VPP has levelized cost of energy (LCOE) of AUD 70-130 per MWH, which is generally lower than that of the fossil fuel-based generators which ranges from AUD 100-300 AUD per MWH.

- In summary, the feasibility of the VPP potential deployment in Bendigo is time-sensitive and dependant of the capacity of PV and battery system. It is recommended that the priority be the ramping-up of the rooftop PV installation program along with the uptake of BESS systems before deploying a VPP system. When the PV coverage reaches 25%-50% of the Bendigo's available rooftop, the VPP system will become an effective management strategy to further increase the value of renewable energy systems. Reaching this level of coverage and beyond may require the use of new technologies such as building integrated PV (BIPV).

- At current demand growth rate as forecasted in Australian Energy Update 2020, the net zero carbon emission cannot be achieved with rooftop PV and home battery systems alone. Other technologies such as solar heating & cooling, EV, large-scale solar and energy storage systems, etc could be considered to further offset the carbon emission.

- Adopting P2P trading in community level can comparatively reduce the energy bills for a high energy user, reduces non-renewable energy intake from the national grid, and increase return for the household prosumers.

- A good auction-based game theory mechanism design can motivate participants to bid the true valuation of PV energy of the electricity market in time to avoid sometimes extremely high energy price in the national grid.

In the longer term, P2P trading can encourage energy self-sufficiency and local consumption of locally generated renewable energy. With the City Council as the initiator, facilitator or investor, the renewable energy P2P trading has the potential to enhance the local control and energy resilience and facilitate energy goals of high energy users.

## 4.2 Recommendations

- It is recommended that the City advocates for and pursues a rapid growth in both rooftop PV and BESS systems. The ideal estimated growth rates are 132.5 MW/year for rooftop PV and around 7,800 units/year for BESS (unit capacity of 13.5 kWh). With this rate, the study area is expected to achieve demand offset of 48.36% in 5 years and 67.98% in 10 years based on the demand rate estimated by the Australian Energy Update 2020.

- This project identified the communities that have the most significant improvement of economic values and carbon emission reduction with extra battery system capacity. The City should advocate  for increasing the incentive for these communities outlined in the table below:

| **Region (SA2 Name)** | **SA1 Code** | **Dominant demand pattern** | **IRSAD Score** | **PV Capacity (MW)** | **Battery Capacity - MWH (Low)** | **Battery Capacity - MWH (High)** | **NPV improvement** | **Carbon emission reduction improvement** |
|---|---|---|---|---|---|---|---|---|
| Flora Hill - Spring Gully | 2102114 | A | 1005 | 1.85 | 1.29 | 2.59 | 93.75% | 34.97% |
| White Hills - Ascot | 2102506 | R | 898 | 2.41 | 1.69 | 3.37 | 84.49% | 45.94% |
| Bendigo Region - North | 2103207 | A | 948 | 0.23 | 0.16 | 0.33 | 78.65% | 40.23% |
| California Gully - Eaglehawk | 2101924 | R | 852 | 1.18 | 0.83 | 1.65 | 78.05% | 33.08% |
| Bendigo | 2101822 | R | 1056 | 1.94 | 1.36 | 2.71 | 56.97% | 35.40% |
| Kangaroo Flat - Golden Square | 2102203 | A | 853 | 2.10 | 1.47 | 2.94 | 55.60% | 34.82% |
| California Gully - Eaglehawk | 2101906 | A | 993 | 2.16 | 1.51 | 3.02 | 70.51% | 36.11% |
| California Gully - Eaglehawk | 2101911 | A | 848 | 1.65 | 1.15 | 2.31 | 66.02% | 41.50% |
| White Hills - Ascot | 2102503 | C | 995 | 5.77 | 4.04 | 8.07 | 72.73% | 27.78% |
| Bendigo | 2101821 | C | 1077 | 2.56 | 1.79 | 3.59 | 90.98% | 26.12% |

- With current level of PV and battery system capacity, community-based VPP is not a financially viable option. However, within 5 years - 10 years' time, with the expected growth of solar and batteries, VPP has great potential to support the City's future growth of renewable energy system and unlock the distributed system's values among the communities. It is therefore recommended that the City prepare for the potential deployment of the future VPP network among communities. For example, conducting further feasibility studies that cover electricity distribution network infrastructure, frequent update of renewable energy uptake data, and trail implementation of VPP in the communities.

- The below communities are considered suitable for trialling VPP systems as they have higher socioeconomic scores and higher forecasted net present value when deploying VPP:

| Region (SA2 Name) | SA1 Code | Dominant demand pattern | IRSAD Score | PV Capacity (MW) | Battery Capacity (MWH) | 25 years NPV (Millions AUD) | LCOE (AUD/MWH) | Carbon emission reduction (t-CO2) |
|---|---|---|---|---|---|---|---|---|
| **Strathfieldsaye** | 2102401 | A | 1105 | 3.57 | 4.99 | 6.1850 | 98.37 | 673.28 |
| **Bendigo Region - South** | 2102614 | A | 1097 | 2.94 | 4.12 | 7.7284 | 81.38 | 731.33 |
| **Bendigo Region - South** | 2102616 | A | 1094 | 3.46 | 4.84 | 8.1010 | 90.87 | 718.64 |
| **Strathfieldsaye** | 2102410 | R | 1092 | 6.64 | 9.30 | 11.0733 | 63.74 | 149.47 |
| **Bendigo Region - South** | 2102603 | A | 1088 | 0.40 | 0.55 | 12.2569 | 78.75 | 87.82 |

- It is recommended the Council maintain frequent updates on the renewable energy data, such as installed system capacity, usage and generation. This information is of great value for advising the future development and calibrate renewable energy transition strategies. Alternatively, the Council could advocate to Victorian government agencies on their interest in the work performed to date and opportunities to advance the data collection and ongoing maintenance moving forward.

With the anticipated renewable energy growth and the expansion of renewable powered economy in the Greater Bendigo region, the City has the potential to become a driving force in the Central Victorian Greenhouse Alliance (CVGA) roadmap to lead the renewable energy transition in the Loddon Mallee Regional.

The challenge still existing is that a renewable energy transition comes with the requirements for financial capability as well as community support and awareness. Both VPP and community renewable energy P2P trading have great potential to support the Greater Bendigo ambition in transition to renewable energy.

Through this project, a knowledge-sharing platform for the broader public to access the research tools, data and results supports the communities' awareness of the renewable transition as well as to advocate future investment and decision-making.

The data resulting from this project has the potential to benefit all regions in Victoria in terms of the tailored renewable energy management strategies and mapping renewable energy data.

There is also the potential benefit for Victorian government decision-makers within the climate and renewable energy units to utilise the data to inform polices.