POWERING A GREENER FUTURE – ASSESSING THE REAL WORLD BENEFITS OF SOLAR PV FOR WATER UTILITIES

Laurence Jenner (Green Energy Specialist), Watercare Services Ltd.

ABSTRACT

Solar photovoltaics (solar PV) are fast becoming the go-to renewable electricity source on the global stage and water utilities are uniquely placed to take advantage of this technology.

Businesses and other entities ranging from oil refineries, electricity generators and warehouses through to schools and households now have the ability to generate free, renewable electricity at an affordable cost. Only a few years ago this was out of reach for most, but reductions in capital costs mean that financially-savvy and environmentally aware businesses should now take another look at solar PV as a viable solution.

This paper highlights the expected benefits of 'behind the meter' solar PV at water utilities using marginal land assets to add value and help meet strategic objectives. We will examine a number of case studies at Watercare where solar PV has been installed since 2019 looking at project costs, project delivery, supplier capability and real-world solar output data.

The paper provides comparative analysis and will discuss international trends in solar generation and related technologies such as battery storage. We will identify some lessons-learned to assist other water utilities to learn from Watercare's experiences and enable them to make informed decisions regarding the future role of solar PV at their business.

As we head into an era of water sector reform there is ample opportunity for water utilities to 're-energise' their operations using solar PV to secure lasting financial and environmental benefits for themselves, their customers and for New Zealand.

KEYWORDS

Climate change – adaptation and mitigation; Sustainability; Asset management; Three waters reform.

PRESENTER PROFILE

Laurence Jenner is a Green Energy Specialist in the Energy Team at Watercare. His background is in supply chain and he has worked in financial services, health, education and conservation. He is a passionate advocate for environmental issues regarding corporate and social responsibility and improving business efficiency.

INTRODUCTION

Watercare Services Limited (Watercare) provides lifeline services to 1.7 million Aucklanders. Watercare is New Zealand's largest company in the water and wastewater industry and every day we supply more than 400 million litres of water to Auckland. We draw water from 27 water sources, treat it and supply it to homes and businesses via a vast network of pipes. We also collect, treat and dispose of around 410 million litres of wastewater daily, including trade waste from industry.

Watercare carries out significant work to upgrade and build infrastructure in order to maintain levels of service and provide capacity for a fast-growing population. The recently released Asset Management Plan (AMP) is our biggest investment programme to date. Over the next 20 years, we will invest $18.5 billion in water and wastewater services, which is an average of $2.5 million every day.

Operating the water and wastewater network across the large geographic area that is Auckland requires a significant level of pumping and treatment, all of which relies on electricity. In FY20/21 Watercare consumed about 200 GWh of electricity, an increase of 2% on the previous year and 20% more than FY17/18, primarily due to lower lake storage levels and greater use of more energy-intensive sources such as the Waikato Water Treatment Plant (WTP).

Watercare generates up to 30% of its total electricity use from biogas cogeneration at the Mangere and Rosedale Wastewater Treatment Plants (WWTP), solar PV generation and from hydroelectricity at dams in the Hunua Ranges. However, the energy output from the latter is increasingly drought constrained. The balance is from imported grid electricity totalling 144 GWh in FY20/21 with associated costs of $16.5 million.

DISTRIBUTED GENERATION

In a previous paper for Water New Zealand *Innovative Energy Opportunities For Water Utilities* (Jenner & Suniula, 2018) we identified a number of operational challenges and opportunities for water utilities in the energy space that can be addressed through distributed generation centred on solar PV. These are:

- Security of supply and resilience
- Manage Time of Use (TOU) electricity & lines costs
- Maximise generation & revenue potential from marginal land assets.

To this list we can add:

- Contribute to greenhouse gas emissions reduction targets.

As previously noted, the deployment of 'behind the meter' on-site generation known as distributed generation using solar PV is one of the simplest and most effective ways to reduce reliance on the grid/augment centralised electricity supply.

Solar PV is accessible and affordable in ways that wind and hydro often aren't. It does not require sustained wind flows or adequate lake levels in order to be viable, and can be fitted relatively easily to existing roof, land and pond assets without requiring hilltop land holdings, extensive civil works or transmission line upgrades.

DRIVING BEHAVIOURAL CHANGE

Distributed generation can help drive improved operational behaviour and efficiency. Using on-site solar PV generation, water utilities with network storage capacity can modify their traditional operating regime and seek to pump more during daylight hours when solar PV provides essentially free electricity and avoid peak TOU rates in the morning and evening.

For example, a 500kW solar array will produce about 720,000 kWh per annum. If only 50% of pumping activity can be reprogrammed to take advantage of peak daytime solar output, at an average TOU price of 10 cents per kWh the gross benefits are $36,000 per annum. Using a recent wholesale price of 21.8 cents per kWh ($218/MWh) the gross benefits would be $78,000 per annum. These savings are a useful incentive for change in any organisation.

COMPLEMENTARY TECHNOLOGY & RESILIENCE

Distributed generation using solar PV is complementary to other technologies including battery storage and emerging technologies such as 'green hydrogen' production via the electrolysis of water.

When combined with battery energy storage systems (BESS), treatment plants and pump stations can be powered at night-time using stored solar electricity. Batteries can also supply backup power and provide additional time for maintenance teams to get to site before diesel a generator is required should the outage last for many hours or days, thus enhancing network resilience.

This provides opportunities to shift loads and costs to off-peak times to deliver financial gains and help avoid incidents such as wastewater overflows caused by lines outages during storms. The latter not only has obvious water quality benefits but is invaluable in terms of public perception and maintaining a water utility's social license to operate.

REDUCE EMISSIONS

Perhaps most importantly, solar PV could be the keystone in efforts to reduce operational emissions from energy use. Using the Ministry for the Environment's emissions factor for the New Zealand electricity grid of 0.101kg/CO_2e per kWh, the 500kW array in the example above would eliminate 69 tonnes of CO_2e per annum, totalling 1,730 tonnes over the 25-year life of the array.

While the grid is already up to 83% renewable, in a dry year this figure can drop to around 68% as more thermal sources are used, as already witnessed in 2021. Without action by centralised generators and by businesses deploying distributed generation, New Zealand will not achieve its 100% renewable electricity target at a time when the electrification of transport and process heat is expected to more than double total electricity demand from 40 TWh to 90 TWh per annum by 2050 (Transpower, *Energy Futures Te Mauri Hiko*, 2018).

Renewable electricity is a key enabler of the electrification of transport and process heat, which together comprise about 30% of New Zealand's total emissions (Productivity Commission, *Low Emissions Economy*, 2018). Water utilities are well-placed to contribute to this energy transition by deploying on-site solar PV.

POWERING A GREENER FUTURE

MEETING OUR TARGETS

There is a global focus on reducing emissions with a goal to keep global warming within 2 degrees Celsius. It is widely acknowledged that emissions need to be at net zero levels by the second half of the century. Watercare has adopted a target of net zero emissions by 2050 as well as a nearer term goal to reduce operational emissions by 50% by 2030 (from a 2018 baseline). These targets are challenging, especially in the face of sector trends that are leading to increased emissions:

1. Population growth and therefore more demand for water and wastewater services and infrastructure;
2. Increased energy intensity of new water supplies that are not gravity fed or are emerging such as wastewater reuse or desalination; and
3. Increased energy intensity of wastewater treatment technology to meet discharge requirements.

Alongside wastewater treatment, energy is one of the major levers we can use to control our operational emissions and meet our climate action targets. While the national grid is highly renewable it still has a portion of greenhouse gas emissions from renewable and fossil fuel-based thermal sources and contributes significantly to the carbon footprint of a company. For this reason, renewable energy that can be readily deployed that utilises land assets and resources recovered from the business such as solar PV, biogas cogeneration and micro-hydro are go-to sources for emissions reductions opportunities in the near term.

COST PRESSURES

Since 2018, wholesale electricity prices have been increasing due to constrained gas supplies and low hydro lake levels. Notwithstanding the closure of the Tiwai aluminium smelter in 2025, prices are expected to continue to trend upwards as demands on existing generation and transmission capacity increase due to population growth, a shift away from fossil fuel-based generation necessitated by New Zealand’s international climate change commitments, and the electrification of transportation and process heat.

Watercare consumed about 200 GWh of electricity in FY20/21, of which 144 GWh was imported from the grid at a cost of $16.5 million. This represents a 20% increase in grid usage since FY17/18 due to greater use of more energy-intensive pumped water sources and a 47% increase in costs over the same period (see Figure 1). Total energy-related costs are now approaching $30 million per annum.

Large-scale solar PV offers the opportunity to generate electricity at a lower price than can be purchased from the grid and provides certainty of fixed costs, acting as a long-term price hedge for 25-years, being the useful life of the array.

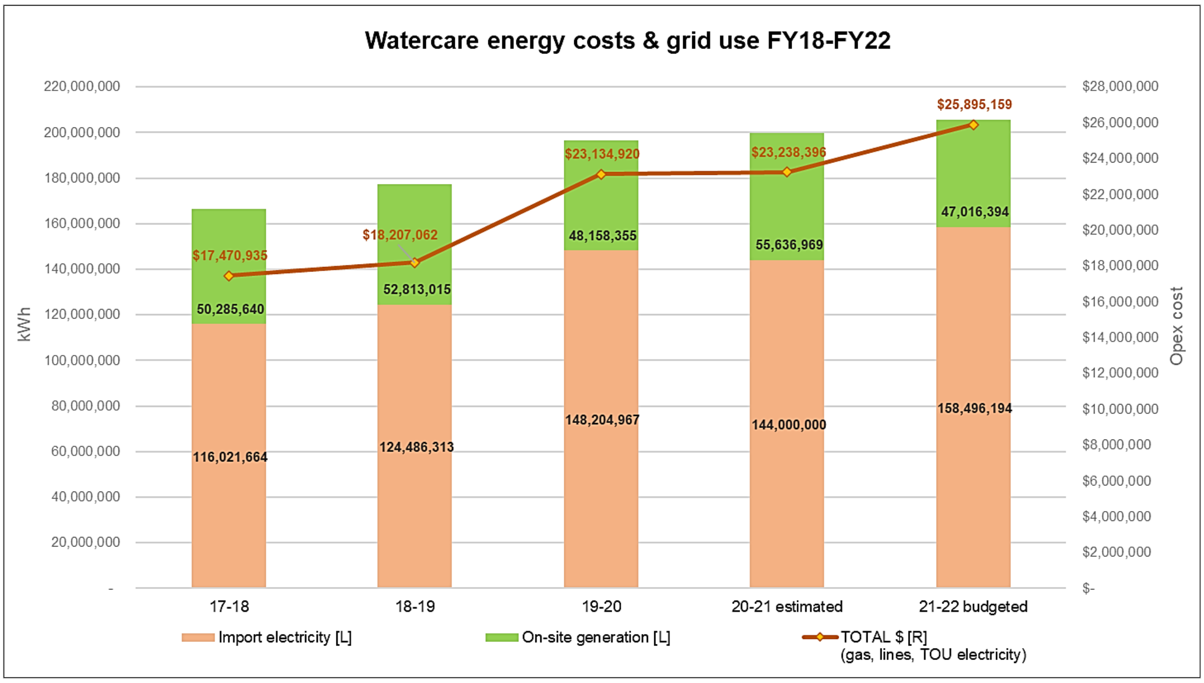


Figure 1: Watercare energy costs & grid use since FY18

NEW WATER SOURCES

Population increase presents a significant challenge due to the pace of growth and geographic distribution. Projections for Auckland indicate a population growing from 1.6 million today to around 2.1 million in 2028 and to 2.6 million by 2043 (Statistics NZ, June 2017), with significant growth on the north shore.

Most of Auckland's low-energy gravity-fed water sources are already at capacity, meaning that future sources must be either pumped from the Waikato River in the south and/or consideration must be given to desalination or wastewater reuse. These water sources are far more energy-intensive and in the case of Waikato WTP, consumes 25x more electricity per m^3 of water produced than our least energy intensive plant Ardmore WTP, which is gravity-fed from the Hunua dams.

These sources also come with the attendant increase in operational emissions and are more complex in terms of consent conditions and stakeholder buy-in. As such, these sites are prime candidates for efforts to reduce energy-related costs and improve resilience. The deployment of on-site solar generation combined with battery storage could ensure that water production is uninterrupted even when ongoing droughts or localised power outages disrupt production at other plants.

OUR PROPOSED APPROACH

Watercare is giving serious consideration to investment in large-scale solar PV and is looking to deploy up to 50MW over the next 10 years. This deployment would:

- Reduce grid electricity import by at least 30% (60 GWh pa)
- Deliver emissions reductions of up to 6,000t CO_2e
- Achieve half of our target to reduce operational emissions by 2030
- Reduce opex energy costs by up to $7 million pa
- Create value from marginal land assets
- Provide certainty of fixed price electricity for 25-years.

Our approach has been informed by experience gained over the last few years in planning, procuring and delivering several small solar projects. In 2019 three solar array projects were completed followed by the floating solar array at Rosedale WWTP in late 2020. Details are shown in Table 1 and site images are attached as Appendix One.

Table 1: Size and output of arrays deployed by Watercare to date

Site	Array size (kWp)	Forecast output (kWh)	Opex savings pa ($)	CO_2e reductions pa (tonnes)
Wellsford WWTP	65	94,000	~$10,000	9
Redoubt Rd Reservoir	142 +225kWh battery	196,000	~$21,000	19
Pukekohe WWTP	122	168,000	~$20,000	17
Rosedale WWTP	1,040	1,486,000	~$160,000	145
TOTAL:	**1,369**	**1,945,000**	**$211,000**	**190**

WHAT WE HAVE LEARNED

Watercare is able to share a range of observations and lessons to assist other New Zealand water utilities with their efforts to decarbonise energy and reduce costs. Hopefully this will enable others to develop strong business cases to deploy solar PV and reach the right outcomes faster for the wider benefit of customers and for climate action:

- **Operation of solar PV:** Solar panels absorb photons (light) from the sun and the silicon and conductors in the panel convert this light into DC (direct current) electricity. This flows into an inverter, which converts the DC electricity into AC (alternating current) electricity, which is the form of electricity used on the grid to power appliances in most countries. Note – batteries store energy as DC.
- **Cost of operation:** Utility-scale solar PV is recognised as the cheapest form of energy on the planet with an LCOE[1] of $36-$44 per MWh, having fallen in cost by 89% between 2009 and 2019 (Lazard, LCOE version 13.0, Nov 2019).
- **Array size & yield:** Arrays are presented as being a certain size or having a certain output. The former refers to peak power output (kWp or MWp) and the latter refers to energy output over time (kWh or MWh). A 5MW array is the DC 'nameplate' size but AC output from the inverter(s) will be less than this – typically about 85%. The yield of an array is presented as annual output kWh divided by kW and in New Zealand this should be around 1,400kWh/kW.
- **Array output:** It is a misconception that solar PV is suitable only for deserts and hot climates. This is incorrect as irradiance from the sun is different to ambient temperature on the ground. In fact, solar arrays lose efficiency in high temperatures. Irradiance is the amount of power received from the sun

[1] Levelized Cost of Energy (LCOE) is used in energy publications to compare the cost of building and operating a power plant over an assumed lifetime for various renewable and non-renewable energy sources. It measures lifetime costs (e.g. build cost, fuel costs, maintenance costs) divided by total energy production and is presented as $ per MWh.

per m^2. New Zealand is perfectly suited to deploying solar PV and is in the same irradiance zone as coastal New South Wales and Victoria. It is superior to most parts of Europe where solar PV has supplied up to 40% of Germany's grid electricity (TIME Magazine, www.time.com/5824644/germany-coronavirus-solar/, 21 April 2020).

- **$ per Watt**: The installed array cost including all equipment costs (e.g. panels, inverters & mounting system), installation labour costs, balance of system costs (e.g. cabling, connectivity equipment) and freight to the site. It excludes any feasibility costs (e.g. geotech) and electrical integration costs into your plant.

PROJECT PLANNING

Every project should have a clear purpose or intent. Solar PV lends itself to multi-faceted business cases that recognise the value of the following benefits:

1. Opex cost savings or revenue; and
2. Emissions reductions; and
3. Improved resilience/energy self-sufficiency; and
4. Enhanced social license.

Ideally each project will deliver a positive Net Present Value (NPV) over a reasonable payback period, but each site is different. A project focussed on avoiding power outages might only have a breakeven NPV but still deliver strong resilience and reputational benefits if wastewater overflows can be eliminated.

Our rule of thumb when assessing the benefits of solar PV at a site is to reduce the grid consumption of the plant first using nearby marginal land assets, then consider revenue benefits from exporting solar electricity to the grid. This provides greater certainty as we know the price of our electricity contracts, whereas exporting to the grid is subject to wholesale market price variability.

It is important to have a good understanding of the energy use profile at your site. This means TOU sites are best as they have half-hourly metered data and are typically higher energy-demand sites. TOU demand can then be matched with forecast array output and a contract rate (c/kWh) applied for each period. This will provide the solar electricity used, exported and the total financial benefits.

Solar output (kWh) can be easily forecast with most models allowing for seasonal cloud cover and storms. Available models include but are not limited to: NREL PVWatts (US based); NIWA Solarview; fee-based software such as PVSyst and Helioscope.

All solar installers will have a forecast tool and you should expect to be provided with month-by-month output summary data similar to that shown in Figure 4.

A rule of thumb to assess the land area requirements (m^2) of a proposed array is difficult as each mounting type (roof, ground, floating) will be configured differently based on the site layout. Very generally, five $1.92m^2$ 380W panels will fit flat into $10m^2$ but in reality, less than 60% of that area may be usable.

Worked example:

Rosedale 1,040kW floating array = $9{,}500m^2$

$9{,}500m^2$ divided by $1.92m^2$ = 4,948 panels but only 2,736 x 380W panels fit

2,736 divided by 4,948 panels = 55% usable area.

PROCUREMENT & IMPLEMENTATION

The New Zealand solar Engineering, Procurement & Construction (EPC) market is moderately well-developed but with significant differences in track record, capacity and product costs between utility-scale installers and the residential scale installers that you see advertised on TV. To date, Watercare has worked with three of four larger installers and we are aware of several mid-level EPC suppliers.

We have generally left the EPC supplier to vet and select their own products using their established supply chains, leaving Watercare to compare traditional price and non-price attributes in any competitive procurement process. Contract form has been Design & Construct.

Solar PV has very strong economies of scale. Significant differences can be expected in the $ per Watt of a small-kW residential array compared with a MW-scale array (see Table 2). Therefore, it is generally better value to identify fewer larger sites than it is to deploy numerous small-scale arrays, but this will depend on the purpose of your project.

Table 2: Indicative prices of roof & ground-mounted arrays observed since 2018:

EPC cost	<10kW	50-100kW	100-200kW	1MW	5-10MW
$ per Watt	$4.00	$2.00-$3.00	$1.30-$2.50	$1.20-$1.70	$1.10-$1.40

A lesson learned is that the cost of electrical integration with an array into a 'brownfields' site can be proportionally quite expensive. New switchboards, transmission lines and even perimeter fences will add substantial cost. Budgets should allow about 30% of the total for these costs.

PROJECT OUTCOMES

Ultimately, the success of a project is measured on if it achieved its objectives and its expected benefits.

For Watercare, we can confidently say that Yes, our solar PV projects completed to date have met their stated objectives - be that learning how to build and operate the technology or delivering emissions and cost reductions for the bottom line.

A key metric is forecast array output versus actual output. These findings are shown in Table 3.

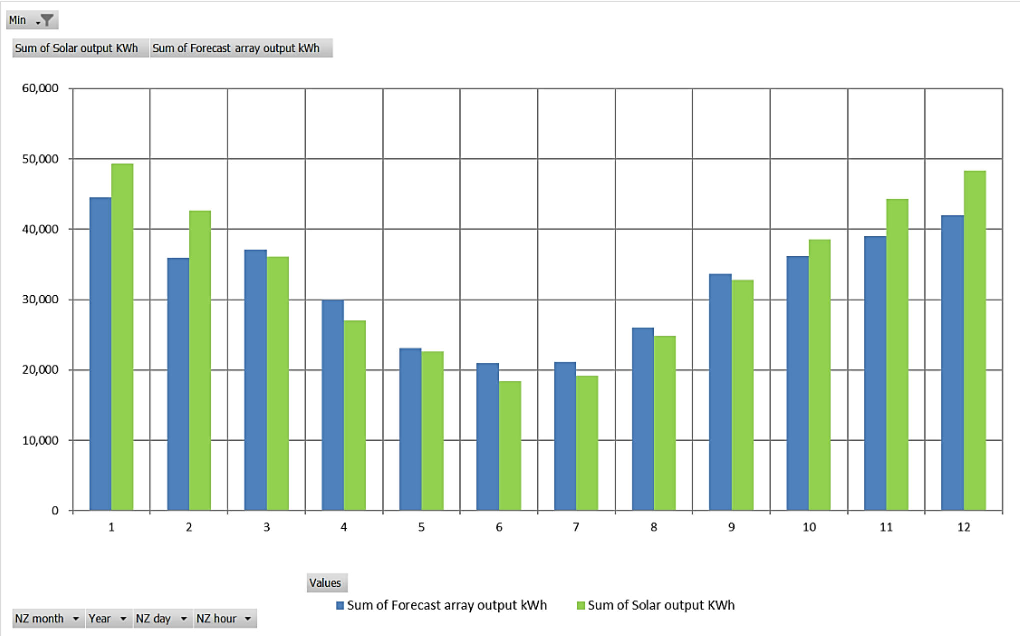
Table 3: Forecast array output versus actual since installation:

Array location & install date	Forecast annual output (kWh)	Forecast output to date (kWh)	Actual output to date (kWh)	Variance %
Pukekohe (1/2019)	168,000	401,500	399,700	-0.005%
Redoubt Rd (7/2019)	196,000	391,700	406,300	+0.037%
Rosedale (9/2020)	1,486,000	1,215,000	1,188,600	-2.1%

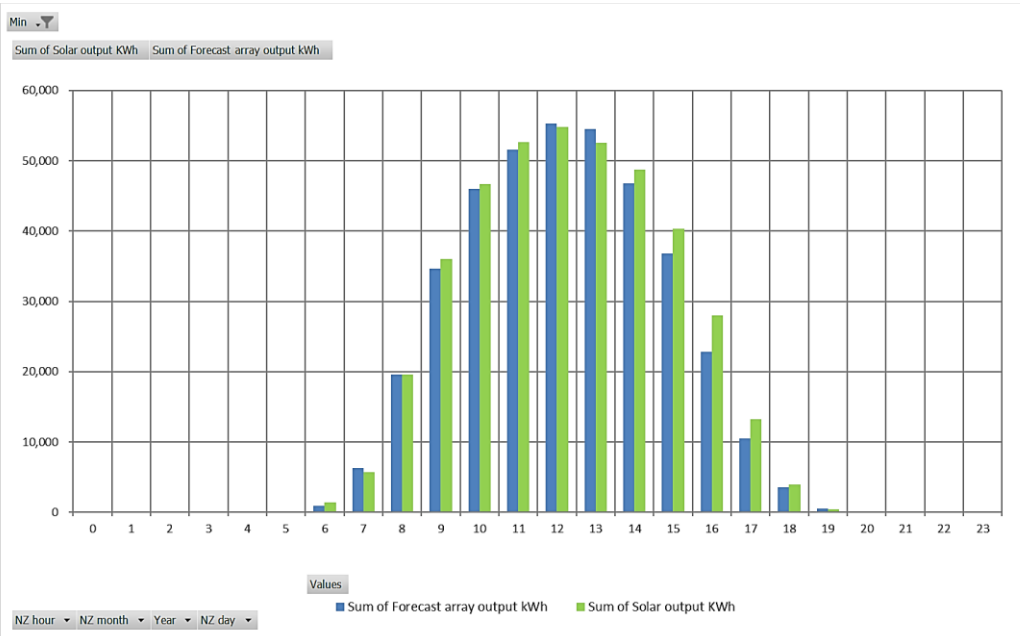
The array at Redoubt Road has performed well to date. Since July 2019, this site displays higher summer output and lower winter output than expected and shows the same over-production in the afternoon compared to the morning as at Rosedale (see Figures 2 & 3). This suggests that arrays in New Zealand could benefit from being oriented slightly West of 0 degrees to exploit more afternoon solar irradiance.

Like Rosedale, these roof-mounted panels are tilted at 11deg, as opposed to 25-30deg for most ground mounted arrays, in order to minimise wind loading.

<u>Figure 2:</u> Redoubt Rd array output – forecast versus actual by month (kWh)



<u>Figure 3:</u> Redoubt Rd array output – forecast versus actual by hour (kWh)

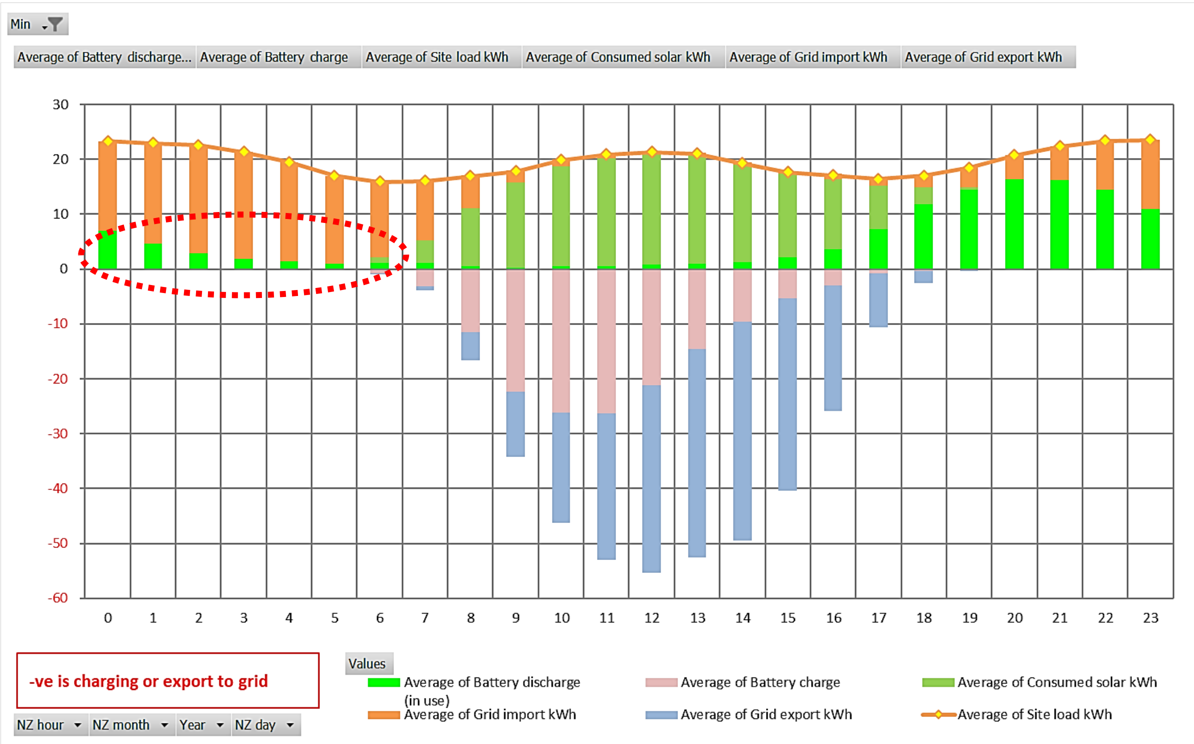


Finally, the 142kW array at Redoubt Rd Reservoir is noteworthy as it includes a 225kWh Tesla Powerpack battery. The purpose of this installation is to improve resilience at a reservoir that supplies a large amount of Auckland's drinking water. The site load is about 37kW so the battery can provide up to 6 hours endurance (225kWh divided by 37kW = 6 hours), of which 1.5 hours is held as reserve backup power in the event of a local grid outage.

Analysis shows that since commissioning the array has generated 406,300kWh of which 35% was consumed by the plant, 26% was used to charge the battery and the balance 44% was exported to the grid.

This use pattern is illustrated in Figure 4 below and suggests that the site may benefit from another battery to provide more stored power from midnight to 6am (circled), or that the array is somewhat oversized and is exporting too much to the grid. The array was sized with reduced winter irradiance levels in mind to ensure that sufficient solar electricity was available to recharge the battery, rather than allowing a valuable battery storage asset to remain idle during the winter.

Figure 4: Average output, site load & battery use per hour since July 2019 (kW)



CONCLUSIONS

Due to rapidly declining costs in the last five years, solar PV is becoming the most accessible and affordable distributed generation solution globally. This means that businesses such as water utilities, for whom building a power station could not or would not be contemplated even a short time ago, now have the opportunity to achieve their strategic objectives.

Alongside treatment process emissions, energy use is one of the major levers that water utilities can control to reduce operational costs and emissions. Solar PV is complementary to other technologies, in particular battery storage, and can act as an enabler for operational behavioural change and efficiency.

The business case for solar PV is multi-faceted and offers benefits across the four value streams of reduced opex costs, improved self-sufficiency/resilience, emissions reductions and enhanced social license for the business.

Through our preliminary forays into solar PV to date, Watercare has had the opportunity to learn from our early mistakes and demonstrate that the expected benefits are both real and achievable. Solar PV is not the only solution and should sit alongside a diverse improvement programme that includes energy efficiency, biogas cogeneration, hydro and wind and battery storage where appropriate. However, solar PV is a highly accessible solution with a reasonably well-developed supply market, and it is something we can use to drive climate action <u>today</u>.

As we embrace an era of water sector reform, we can have confidence that we do not have to choose between the environment, energy security or sound economics in the pursuit of becoming successful utilities of the future.

ACKNOWLEDGEMENTS

Shane Morgan, Chief Operations Officer at Watercare for his guidance and support.

My wife Rebekah Jenner who passed away in January this year who always encouraged me to pursue my passion for renewable energy.

REFERENCES

Jenner, L. & Suniula, L. (2018) *Innovative Energy Opportunities For Water Utilities*, Water New Zealand.

Lazard, *Levelized Cost of Energy (version 13.0)*, November 2019.

Productivity Commission, *Low Emissions Economy*, 2018.

TIME Magazine, *Germany With Skies Cleared by Coronavirus Lockdown Produces Record Solar Power,* 21 April 2020 (www.time.com/5824644/germany-coronavirus-solar/),

Transpower, *Energy Futures Te Mauri Hiko*, 2018.

NOMENCLATURE

BESS: Battery Energy Storage System.

kWp: kilowatts peak – maximum DC output of a solar array before being converted into AC via an inverter.

LCOE: Levelized Cost of Energy – a measurement of lifetime costs of an energy asset divided by its total energy production.

PV: Photovoltaic or solar cells that convert sunlight into electricity (voltage).

TWh: Terawatt hours, a unit of electricity consumption over time (1 TWh = 1000 GWh).

GWh: Gigawatt hours, a unit of electricity consumption over time (1 GWh = 1000 MWh).

MWh: Megawatt hours, a unit of electricity consumption over time (1 MWh = 1000 kWh).

kWh: kilowatt hours, a unit of electricity consumption over time (1 kWh = 1000 Wh).

NTOU: Non Time of Use electricity tariff usually read monthly.

TOU: Time Of Use electricity tariff monitored half-hourly.

APPENDICES

Appendix One

Site images of the four solar projects completed by Watercare to date:

Wellsford WWTP 65kW array

Redoubt Rd Reservoir 142kW array + 225kWh battery

Pukekohe WWTP 122kW array

Rosedale WWTP 1,040kW floating array