Diverter and Timer Model

Accompanying Appendix Three to

Understanding the value of residential solar PV and storage in New Zealand

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Contents

Disclaimer

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1. Introduction

This appendix outlines the design and operation of the diverter model and timer model. Section 2 describes the diverter model used and the design parameters and assumptions made. Section 3 describes the timer model, which is a special case of the diverter model. Section 4 gives more detailed information on the operation of the diverter model.

2. Diverter model

The diverter model is similar to the one employed in the EECA Gen Less solar tool, with a number of important enhancements and differences outlined in the next sub-section. It operates within the context of the overall solar model by modifying the household load profile at each half-hour. This modification is made prior to the solar model's calculation of solar offsetting load to find a new load (load less solar) and any solar export.

The diverter model increases load in the morning based on available solar generation such that the new load profile is exactly equal to the available solar generation at each half-hour. This continues until the hot water cylinder water reaches its thermostat set point temperature, at which time the half-hourly demand returns to the existing load profile's demand. As hot water use continues, and standing losses reduce water temperature, additional hot water load continues to be added to each half hourly load based on available solar generation. The water temperature is used as a state variable in the model, allowing the determination of energy requirements at each half-hour based on standing losses and hot water use in the morning and evening.

The result of this increased load offset completely by solar generation is a net demand of zero until the water is heated to the nominal temperature. After this, demand returns to its original level, with occasional heating of hot water. In this way the diverter mimics the operation of an actual hot water diverter. Figure 1 and Figure 2 demonstrate the diverter's operation on a winter day – Figure 1 showing modelled operation without a diverter but with solar, and Figure 2 showing the modelled operation with solar and a diverter on the same day.

2.1 Diverter model assumptions

Assumptions made in the diverter model are:

- The diverter uses pulse width modulation (PWM) and can therefore continuously vary its power output from 0 kW to 3.0 kW. No minimum threshold solar excess is considered; therefore, any modelled solar excess is diverted to the hot water cylinder.
- The hot water cylinder heating element is rated at 3.0 kW.
- The cylinder has sufficient volume and is heated to a sufficient temperature to store and supply one day's requirement of hot water. The cylinder volume used in this model is 270 litres, and the maximum temperature of the hot water is 73°C.
- Only the bottom element is used, giving the diverter and solar the ability to completely heat all hot water when there is sufficient excess solar energy.
- When there is insufficient solar energy in a day, the diverter can heat the cylinder from network supplied electricity after midnight in the following day. This is only active between April and September inclusive. This mimics a design by the author for a hot water diversion system supplying two hot water cylinders totalling 570 litres.

- The bypass circuit described is atypical but included to ensure complete heating of all hot water requirements from excess solar energy when it is available, as well as complete heating when there is insufficient excess solar energy. In reality, solar may be connected via a diverter to a hot water cylinder's top element to supplement network supplied electric heating, or may be solely connected to the bottom element, with some days' water heating requirements not met.[1]
- The Eddi diverter, for example, could supply additional power to the cylinder via a timer circuit. Alternatively, the bypass described could be achieved by a separate ripple controlled contactor, which could be enabled only during winter months when there is less solar energy.

[1] This is not advisable, as hot water that is too low in temperature can grow legionella bacteria, which could lead to legionella disease, a serious form of pneumonia.

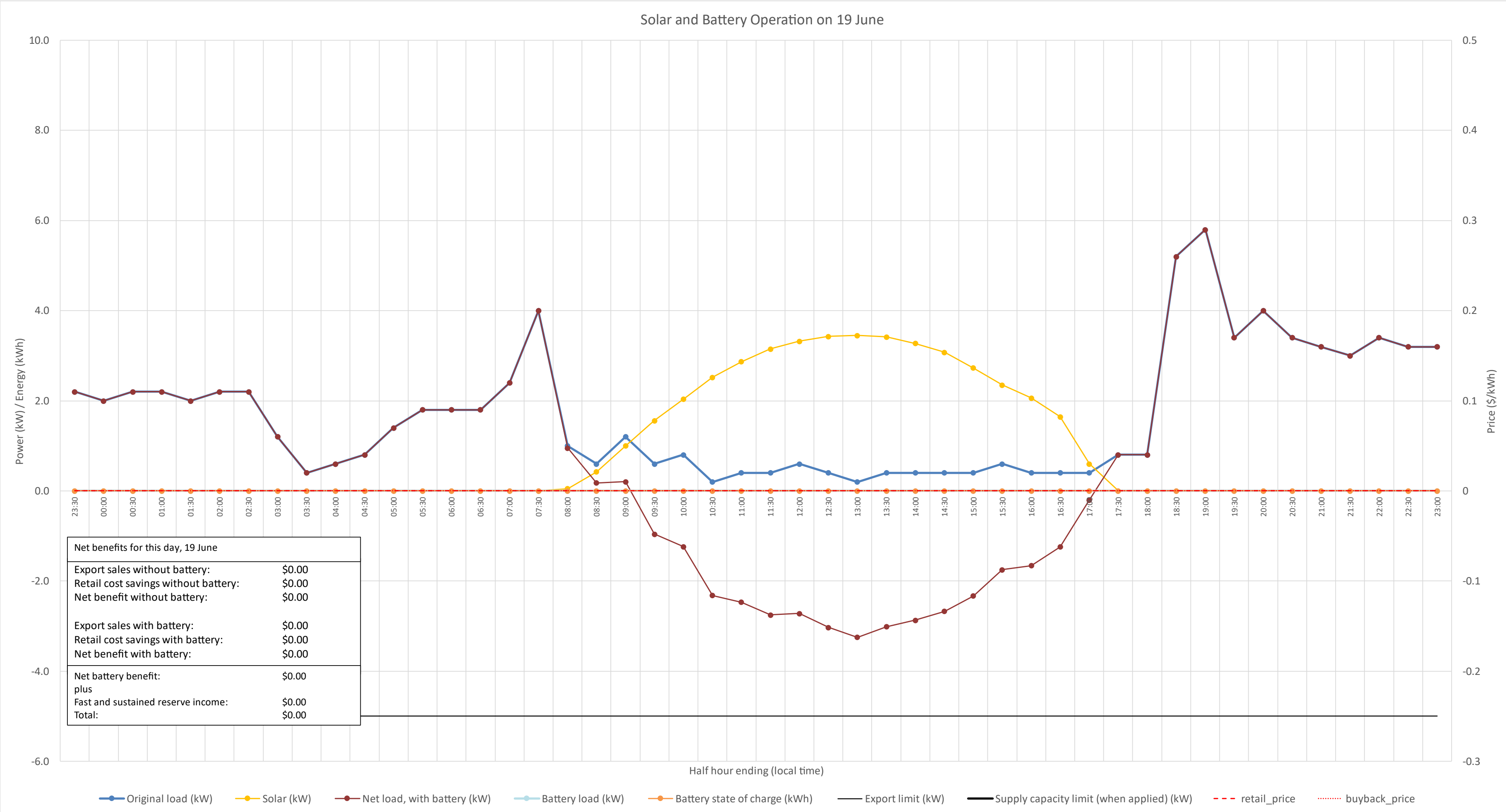


Figure 1: Solar model operation without any diverter or battery, 5 kWp-ac capacity solar. The graph is generalised to examine the performance of any solar model output. In this case, the 'Net benefits for this day, 19 June' breakout details and the battery load, state of charge, supply capacity limit, and retail and buyback prices are unused parameters.

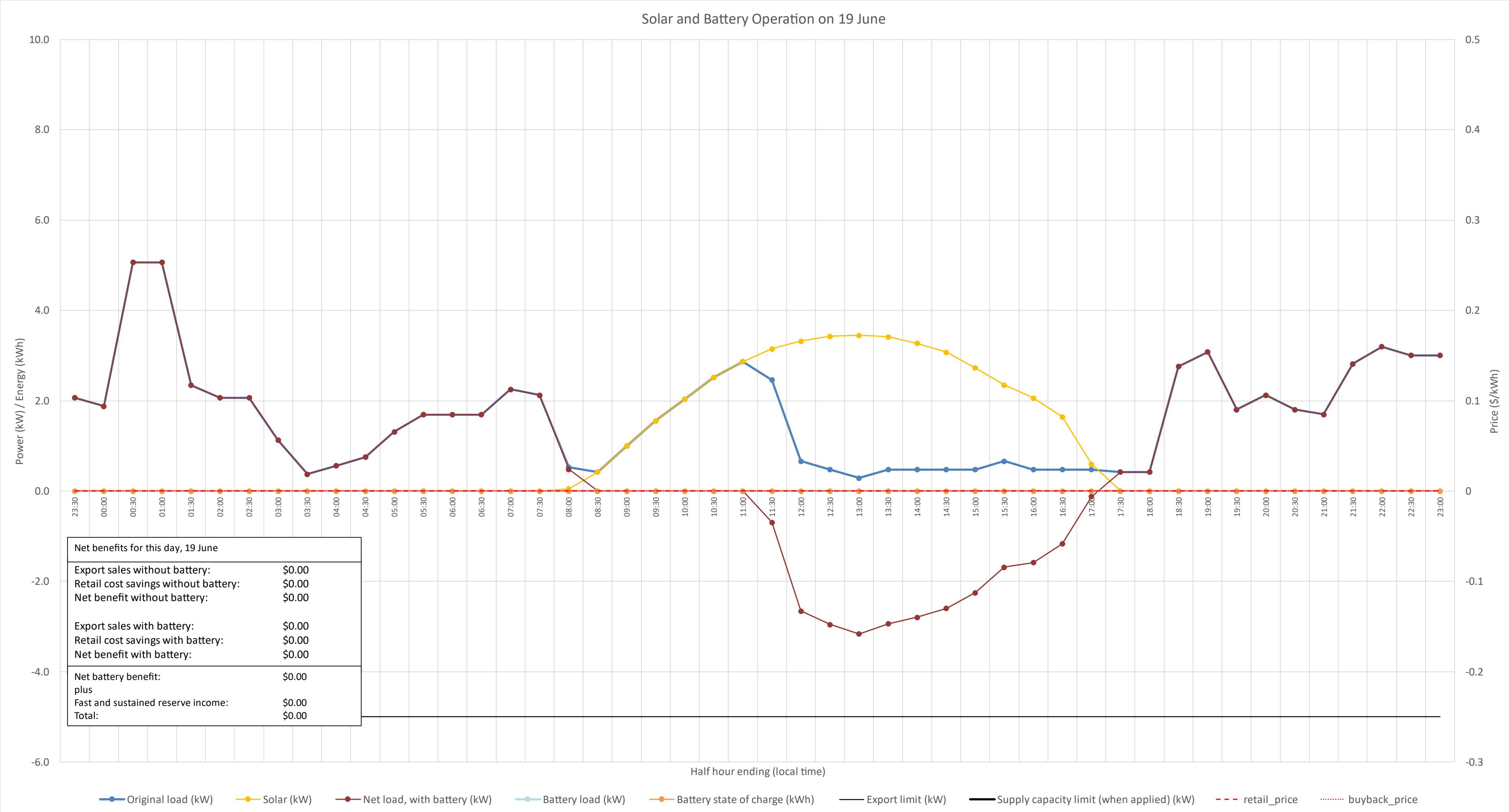


Figure 2: Solar model operation with a hot water diverter, 5 kWp-ac capacity solar. The operation of the diverter during the morning solar generation period results in no export up to 11am, and lower demand from 7am to when solar generation begins, and from 5pm to 9pm due to lower hot water heating demand (because it has been met by solar). The jump in load from 00:30 to 01:30 is the result of the previous day not having sufficient solar energy to completely heat the hot water; the additional energy is then supplied in the early hours of the morning from the bypass device described.

2.1 Diverter enhancements

The following are enhancements to, and differences from the EECA solar tool diverter model.

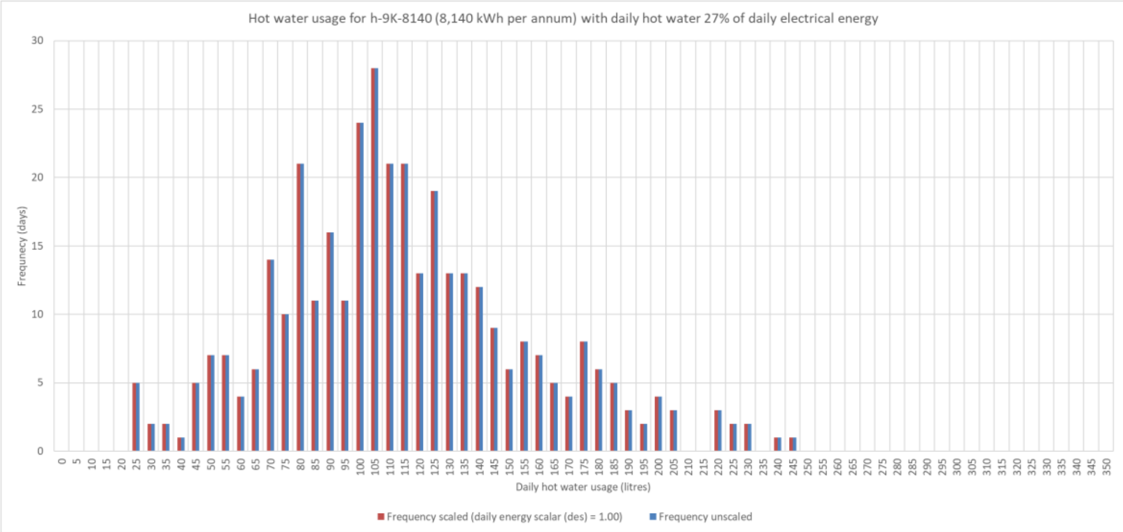
1. The model is half-hourly, rather than hourly as used in the EECA solar tool.
2. Hot water usage is not modelled as an even demand throughout every hour of the day, as assumed in the EECA solar tool model implementation. Instead, in this model it is concentrated in the morning and evening, according to the household occupants' likely use. This time period is from 7-11am and from 5-9pm. Even this is an assumption, as hot water use will be in an uneven pattern, and outside of these periods on occasion.
3. In addition to the above change, standing losses are modelled separately, and occurring at an even rate in every half-hour of the day. The model assumes that 25% of energy input to heat hot water is lost as standing losses. In this respect the model is simple in that it does not consider ambient temperature, nor the difference between hot water temperature and the external temperature which both affect the rate of heat loss.
4. The EECA solar tool determines daily hot water energy by multiplying hourly electrical energy consumption by 27%. The value of 27% is used since it is the estimated annual average proportion of electricity consumption used to heat hot water. This is clearly an assumption, but reasonable in the absence of other information. In this way the EECA solar tool assumes that the daily hot water use is 27% of daily electricity consumption. In other words, the assumption of 27% of annual consumption has been further assumed to be 27% of daily consumption (indeed in the EECA solar tool it is even further assumed to be 27% of hourly consumption – addressed in this model as discussed above).

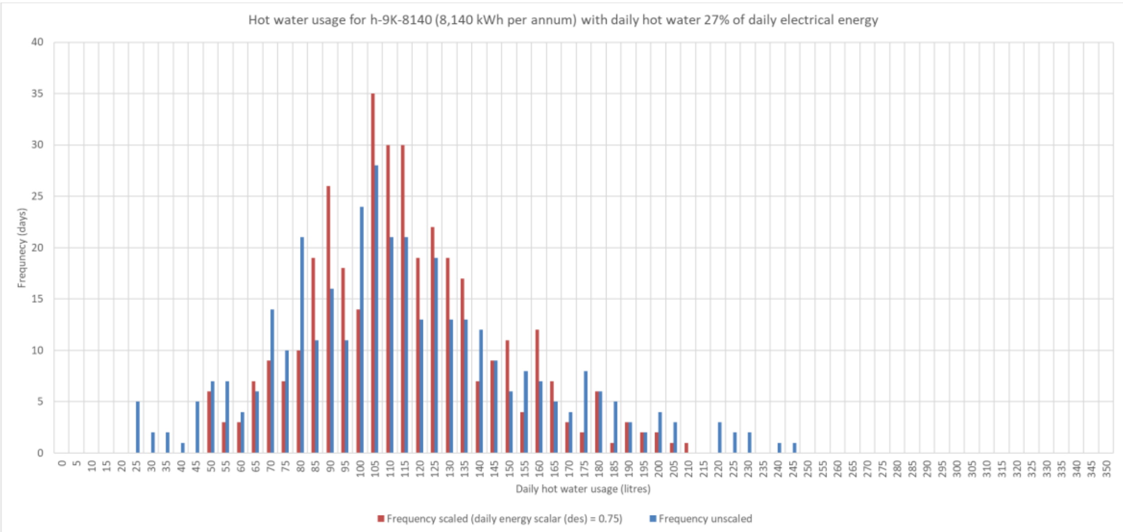
   The benefit of the existing EECA solar tool model's approach is that it adjusts for actual consumption in each day. For example, daily consumption may be very low with hardly any hot water use when the household occupants are away. However, for some households such an approach may skew hot water usage to unrealistically high amounts on days when energy use is high due to factors such as space heating and / or electric vehicle charging.

   In this model, the annual average value is carefully scaled to a daily value based on the daily consumption, but always adds up to the annual amount of 27% of electricity consumption. This is achieved through use of a configurable scaling factor. When set to 0 it determines daily hot water energy from a single value equal to 27% of annual electricity consumption divided by 365 days. When set to one, it determines daily hot water energy use from the daily energy use – equivalent to that used in the EECA solar tool.

   As identified earlier, determining water use on very low electricity use days may be realistic, but on very high consumption days it may be unrealistically high. For this reason, the diverter model in this study uses a scaling factor of 0.75. The graphs in Figure 3 show the results of using a scaling factor, and why a scaling factor of 0.75 is used in this model.

   The graphs in Figure 4 show the modelled hot water temperature at the end of each day. Because of the low minimum values, the maximum temperature was set to 73 degrees (the temperature at which the cylinder's thermostat turns off) and the winter night-time boost function described earlier was implemented. The temperatures presented in Figure 4 assume seasonal variation in supply water temperature from 18°C in the summer to a minimum of 10°C in August.





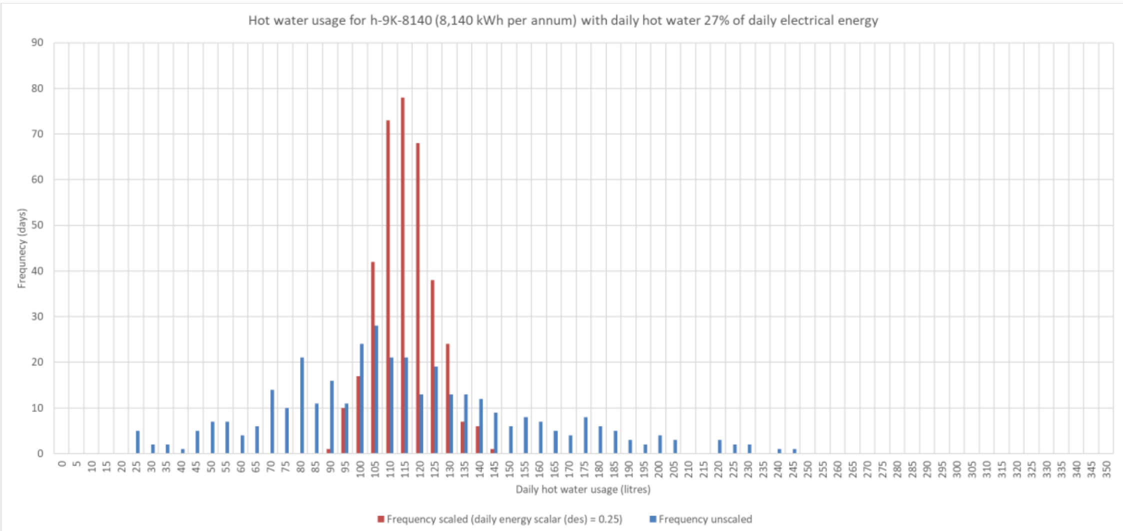
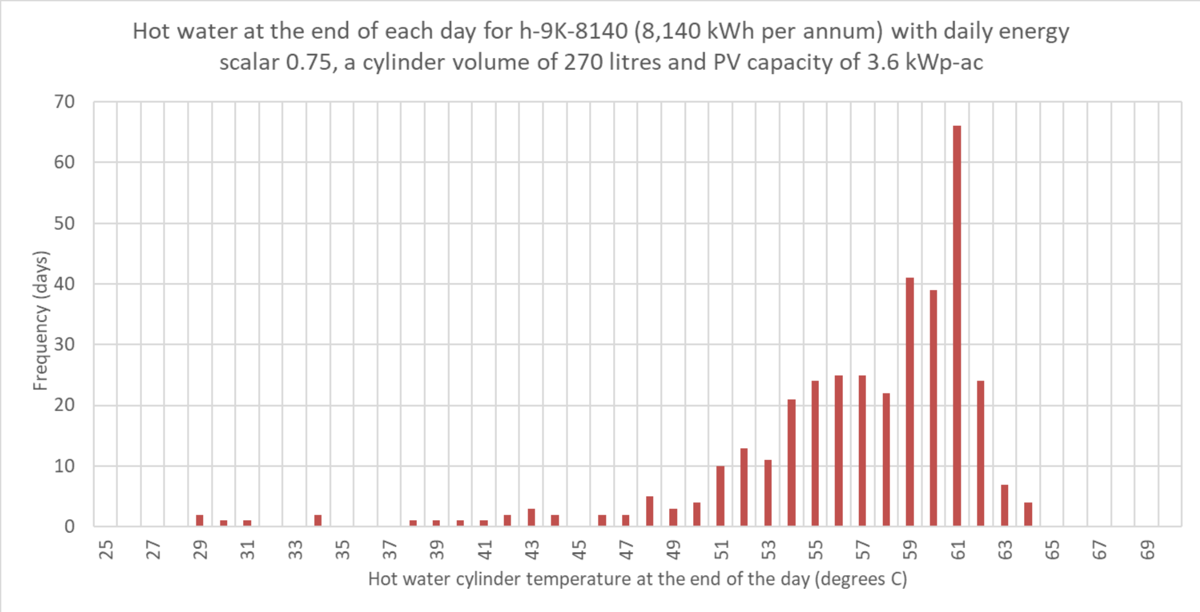
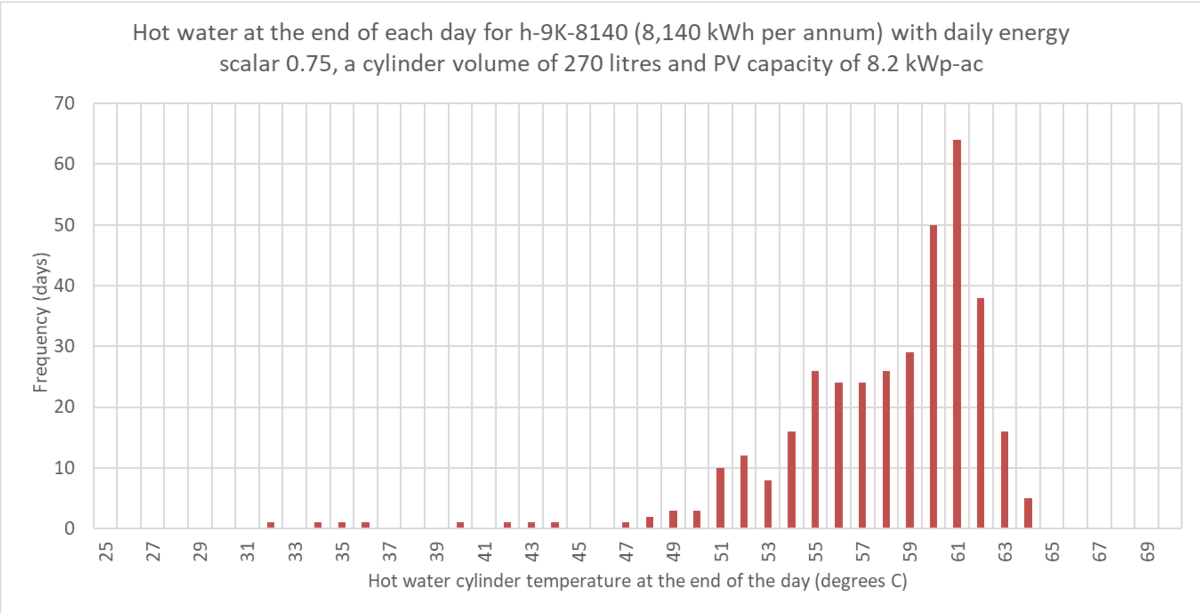


Figure 3: Top: scaling daily hot water use directly from daily electricity consumption (the scaling factor is set to 1). Results shown use a test load profile h-9K-8140. Middle: scaling daily hot water use from a slightly scaled daily electricity consumption (the scaling factor is set to 0.75). This moderates the extremes of daily hot water use but still represents days when hot water use is low. Bottom: scaling daily hot water more closely to annual use. This overly moderates daily hot water use.



(a)



(b)

Figure 4: Hot water temperature at the end of the day with the scaling factor of 0.75 and the same test load profile for: (a) a 3.6 kWp-ac PV system in Christchurch, north facing with a 30 degree tilt angle; and (b) for an 8.2 kWp-ac PV system, same orientation and tilt.

3. Timer model

The timer model uses exactly the same design as the diverter model, but instead of applying power to the hot water cylinder element in equal amounts of excess solar generation, it simply turns on supply to the hot water cylinder between 11am and 3pm (chosen deliberately to be outside of the peak period of most distributors and retailers, but close to the middle of the day when solar generation is close to maximum on cloudless days). In turn the hot water cylinder presents an additional demand equal to the capacity of its element, which is 3 kW. This therefore increases the household's load, which is then provided as a modified load profile to the solar model described earlier. As expected, the hot water load ceases when the hot water temperature reaches the thermostat set point of 73 degrees. The operation of the timer may result in load higher than the solar generation, as shown between 11am and 12pm in the example in Figure 5.

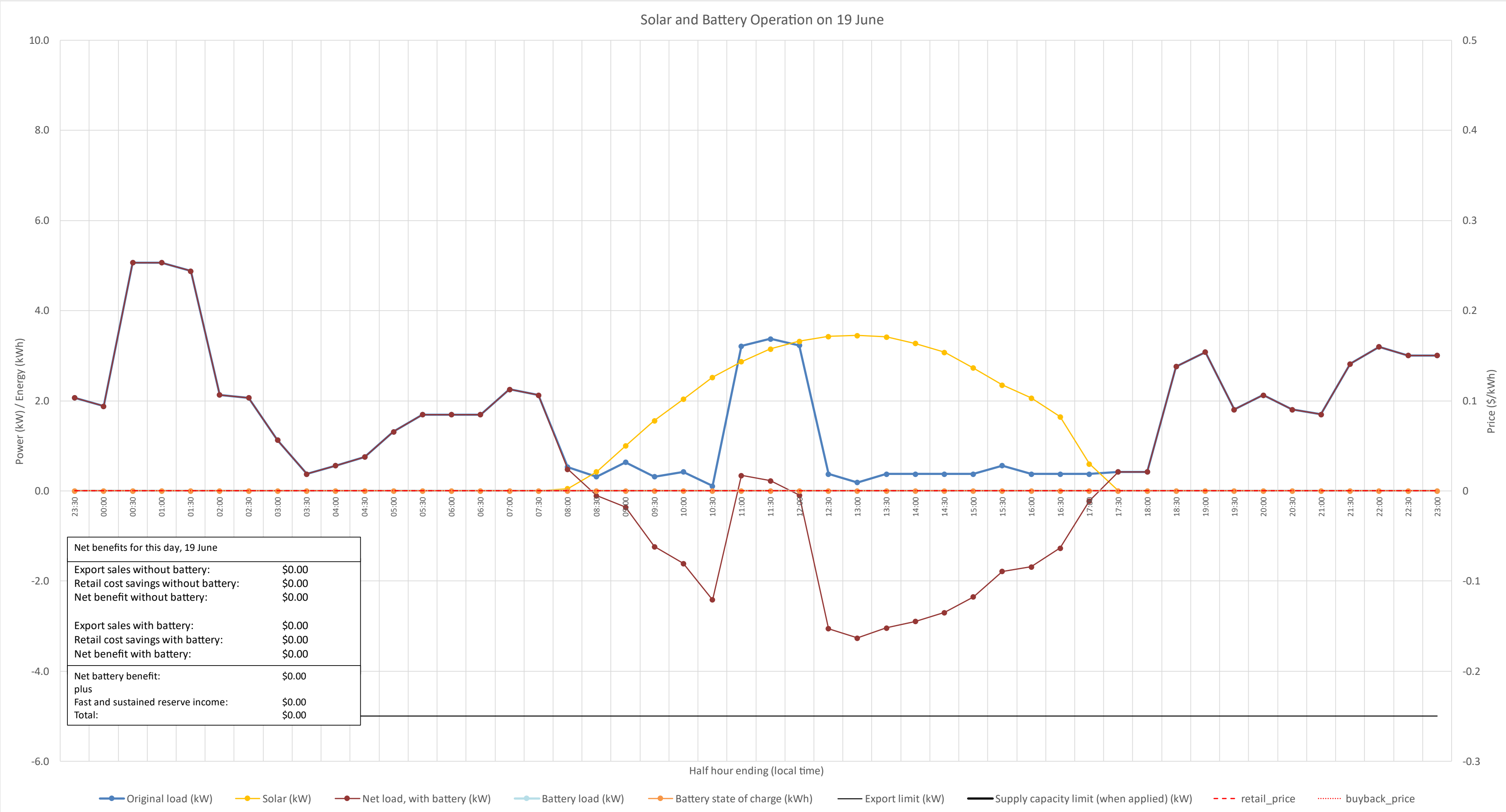


Figure 5: Solar model operation with a hot water timer set to turn on at 11am and off at 3pm, 5 kWp-ac capacity solar.

4. Diverter and timer model operation

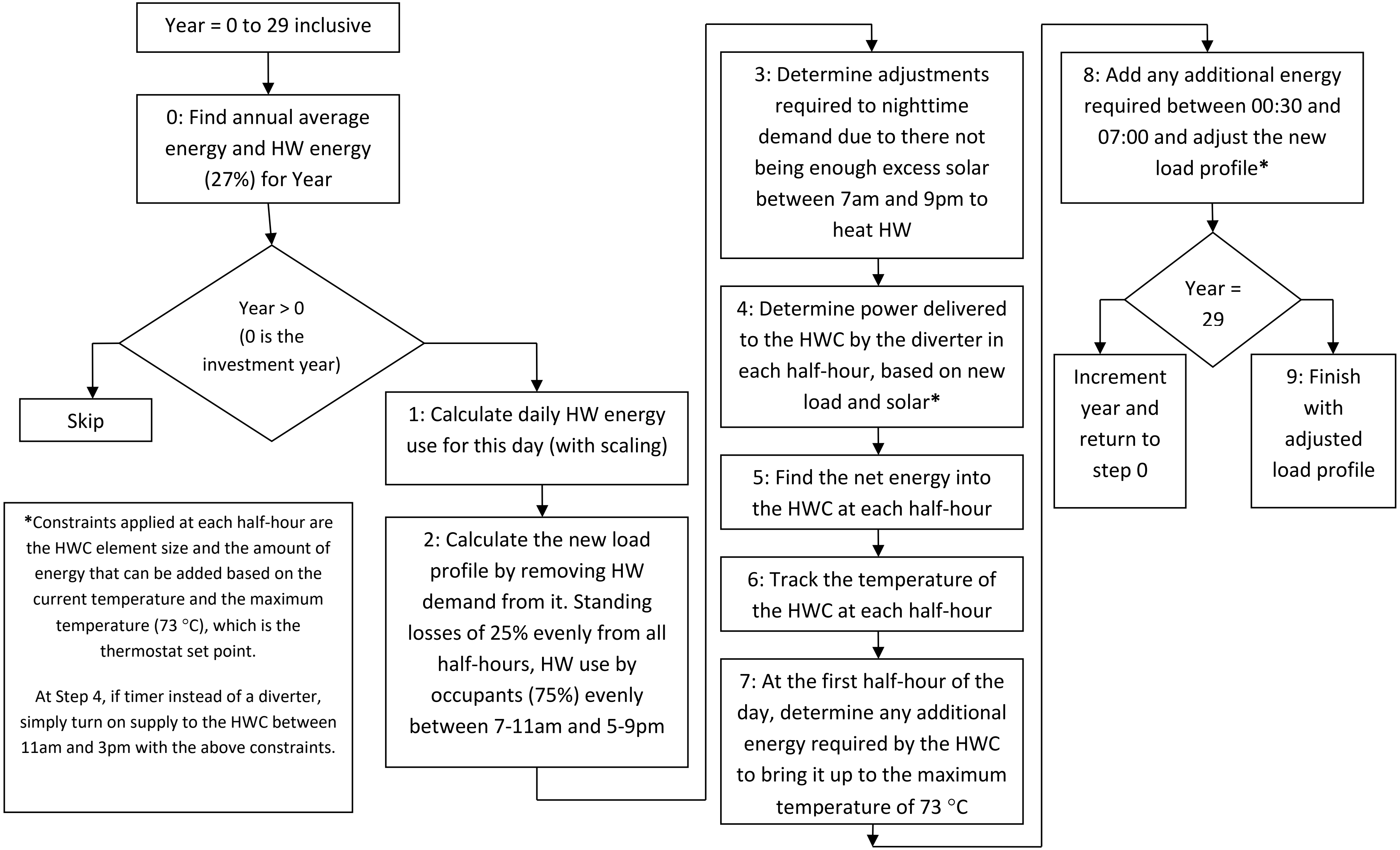


Figure 6: Diverter and timer model operation. Each of the 29 years is modelled separately, as solar generation changes in each year due to light induced degradation of the PV panels.