Community Solar -vs- Nano-Grid (Ownership or Lease) Including Balcony-Solar and Battery-Only Options: 10 Year Electricity Avoided Expense/Savings Cost Analysis For Hawaii Low Income Families

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***Abstract*— The cost of electricity is very high in Hawaii at >40¢/kWh, for low-income families consuming 28kWh/day, the monthly utility bill expense is $341/month, $4.1K/year and $41K over 10-years. Community Solar expected savings of 20%, 10-year electricity expense would be $32.7K for an avoided expense of $8.2K but vulnerable to frequent grid blackouts. Actual reported Molokai Community Solar results show only 4.5% savings. Nano-Grids are resilient to blackouts, ownership payback period is 3-5 years then Free Electricity and over a 10-year period will save $28.8K. Rent-to-Own payback is 8 years for Free Electricity and 10-year savings of $8K. Nano-Grid with 20-year lease/PPA contract with 50% electricity rate reduction to 20¢/kWh, 10-year electricity payment is $20.4K plus $3.8K to utility for grid connection fee ($32/month), avoided expense is $16.7K. Balcony-Solar, small plug-n-play systems (<1.6kW) saves 6% monthly, add equipment costs, estimated payback period is 9.5 years for 10-year avoided expense of $555. Battery-Only (>10kWh) allows Time-of-Use (TOU) rates without solar reducing electricity rate by 50% and can be used by anyone. Payback is <2.5 years and 10-year expense is $25.4K for an avoided expense of $15.5K. Economic sustainability requires energy efficient homes and elimination of home energy waste. Step-1 requires digitization of home energy ecosystem using smart IoT devices for energy monitor and control. Step-2 is take corrective action based on Pareto Analysis of the top home energy loads, switch to the latest energy efficient household appliances such as heat pump washer/dryer and water heater, induction cooking, Energy Star refrigerator/freezer and all LED light bulbs to reduce energy demand up to 56%.**

***Index Terms*—Community Solar, Energy Audit, Energy Star, Home Energy Digitization, Nano-Grid, Lease, Ownership, Balcony-Solar and Battery-Only.**

I. INTRODUCTION

The global mean temperature exceeded 1.5ºC for the first time in 2024 (1.54ºC) but decreased to 1.44ºC in 2025 reported by Berkeley Earth shown in Fig.1 [1]. Every year the atmospheric CO_2 levels on top of Mauna Loa observatory keeps rising, it reached another new record high of 430.5PPM for May 2025, an increase of +3.6PPM shown in Fig.2 [2]. The United States (U.S.) electricity generation has been flat the past two decades at 4 Trillion kWh but now needs to double over the next few years to meet the increased demand from electric vehicle (EV) fast charging peak demand of 50kW/EV and generative AI (Artificial Intelligence) driving new Super Data Centers with power requirements of 2.5GW (a nuclear power plant) with each nVIDIA Blackwell AI chip requiring 1kW power [3,4]. In the US there are 287 million registered cars, if each car was an EV, that would require 12.8x more electricity capacity today. Short-term solutions using gas power turbines are polluting the air, making people ill [5]. Therefore, Fighting Climate Change and decarbonization will require everyone in the U.S. to do their part, quickest way to have an impact starts at home by striving to achieve 100% clean renewable energy and being energy conservation minded as reported by Borland in his invited talk at the 2019 NIST Workshop on PV titled "Fight Climate Change with Solar + Multi-Storage and Island Nano-Grid for Resilience and 100% Renewable Clean Energy Today" [6].

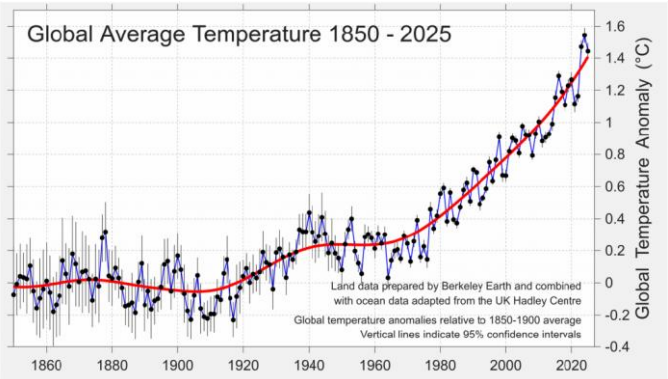

Fig.1: Global temperature rise for 2025 [1].

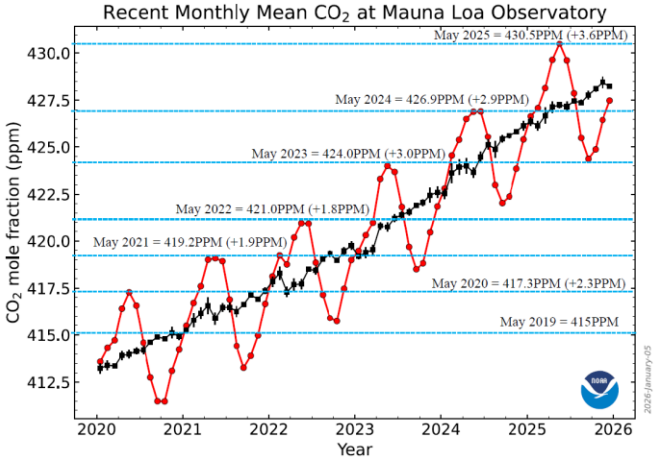

Fig.2: NOAA atmospheric CO_2 levels from 2020 to 2025 [2].

Hawaii has seen a drop-off in residential rooftop solar adoption as the available market has become saturated with those who can afford the $30-70K capital investment costs for solar + battery and those who qualify for the full tax credits have already done so. In the US, only 30% of taxpayers can claim the full tax incentives [7]. Currently, 47% of single-family homes (118K homes) in Hawaii have rooftop solar, the "Haves" who can afford the $30-70K system costs, leaving 130K single family homes and an additional 162K customers living in apartments or high-rise condominiums, the "Haves Not". A total of 332K homes (71%), homeowners and renters do not have solar as shown in Fig.3 including Community Solar and Nano-Grid systems such as Balcony-Solar, Battery-Only or Solar + Battery. Creative financial incentives including direct cash rebates and Rent-To-Own are required for low-income families and can be Life Changing.

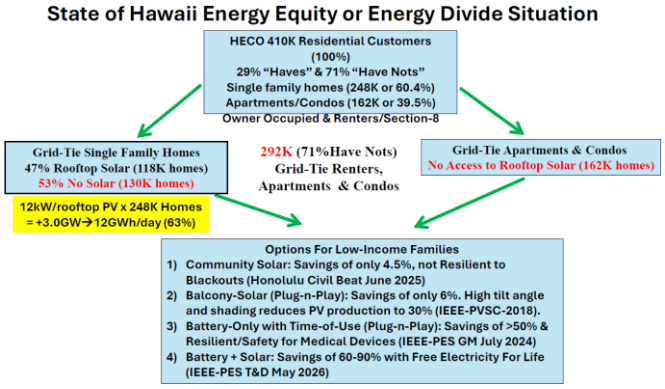

Fig.3: 71% of Hawaii residents do not have Solar, the "Have Nots".

II. UTILITY VS COMMUNITY SOLAR COST ANALYSIS

Over the past decade, many states have committed to100% renewable energy by 2045, unfortunately, results show this leads to increase in residential electricity rates that are passed on to the "Have Nots". This also includes the added costs to make the grid more resilient to high wind, wildfire and other disasters. The affluent solar customers, the "Haves" already pay the minimum monthly utility fee ($32/month in Hawaii), called NEM Equivalent Saving™ by Borland in 2021. After the 3–5-year payback period the "Haves" also get Free Electricity for Life (30+ years solar panel life). The "Have Nots" end up paying these higher utility rates for the rest of their life. Example for average residential electricity rates are plotted in Fig.4 from 2011 to 2026 for Hawaii (Oahu), Molokai, Kauai-Coop and US Mainland. The volatility in oil price ($/barrel) which makes up 80% of Hawaii generation fuel caused 36% jump in electricity rate from 27¢/kWh in 2020 to 45¢/kWh in 2022 due to Ukraine War. Today oil usage has dropped down to 63% with renewables at 37% for Hawaii but the electricity rates has not dropped below 37¢/kWh, the new lows are much higher due to added costs of high wind and wildfire mitigation. Note that daytime Time-Of-Use (TOU) rates are 33-59% lower than regular rates over the past 9 years, currently at 15¢/kWh.

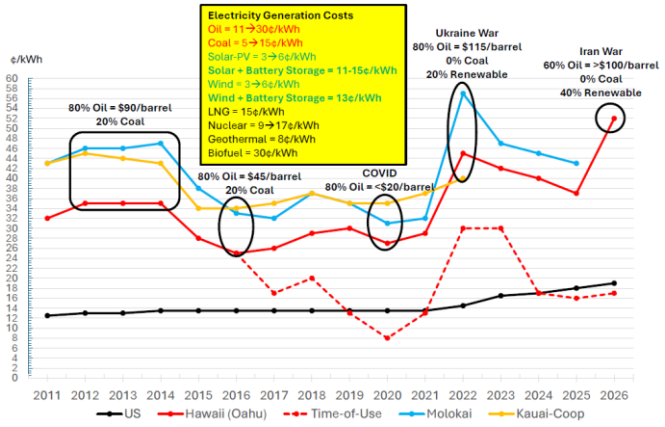

Fig.4: Hawaiian Electric rates from 2017 to 2025 including Time-Of-Use.

To achieve Energy Equity, Solar For All programs have been proposed with Community Solar projects positioned as the best option for underserved communities and low-income families since there is no need for rooftop solar access, also ideal for renters, apartments and condo dwellers. Such programs have been offered in CA (46MW) and HI (4MW) for over a decade with very little interest and small signups or subscriptions while other states like FL (2.1GW), NY (1.8GW) and MA (1.0GW) have many subscribers [8]. A 6/5/25 Honolulu Civil Beat article describes how the Community Solar on Molokai after 2 years only has 15 subscribers "…failing to gain traction in Hawaii…"[9]. The reason may be related to the local utility electricity rates and actual small savings reported to only be 4.5%. Nationwide, the savings for subscribing customers is reported to be between 5-15% not the 20% target savings. Community Solar is also not resilient to blackouts due to power line failures, critical if you have a home medical device or medicine requiring cold storage, then the best choice is a battery backup generator for proactive "Loss of Life" prevention and guaranteed home safety & security [10].

In Hawaii, the main motivation for going Solar + Battery for low-income families, is not to go "Green" and save the planet with 100% renewable energy, it's the economics and reduced energy burden by >70% that switching to renewable energy brings. Saving thousands of dollars over 10 years in avoided expenses making going Green is a bonus. Savings between 70-93% is Life Changing and $3-4K per year

savings in electricity expenses is like earning an extra $3-4K per year (a penny saved is a penny earned). Over 10 years this is $30-40K in avoided expense to the utility to spend elsewhere to improve Quality of Life. Sadat & Pearce reported that when electricity rates are high, the economics suggest Grid-Defection with Nano-Grids is best solution [11].

III. NANO-GRID OWNERSHIP OR LEASE COST ANALYSIS

Only Nano-Grids provide resilience and safety to power outages for most vulnerable families with home lifesaving medical equipment or medicine requiring power 24/7 [10]. Solar + Battery lease programs avoids high upfront equipment costs but in the long run after 10 years, electricity expenses for the lease can save 50% but still cost $20.4K (Fig.5). With ownership, avoided expense/savings is $28.8K and short payback/ROI of 2.5 years due to the high electricity rate then Free Electricity for Life (30+ year solar panel life). This is achieved because of the 35% State of Hawaii and 30% Federal solar incentives shown in Fig.6. With the end of Federal incentives for solar, the 35% Hawaii State solar incentive increases payback from 1.9 years to 3.6 years as shown in Fig.6 based on final system cost estimates. The Iran War pushes oil prices to >$100/barrel and electricity rates to 43-52¢/kWh in Fig.6. When electricity rates dropped to 24¢/kWh in 2020, payback period increased from 1.9 years to 3.3-years and when rate increased to 43¢/kWh in 2022, payback dropped to 1.6 years. Borland's actual case study results after 10 years (June 2016 to April 2026) is shown in Fig.5 going from a 10-year utility payment of $47K to actual savings of $27.3K and only $5.3K payment to the utility. The 35% State incentive and no incentive plots are also shown in Fig.5 for comparison with 5.0-years and 7.5-years payback (economic for Grid-Defection) [11]. My definition of Energy Equity for low-income families in Hawaii is reduce monthly electricity bill to <$40/month with payback of <5 years for Free Electricity.

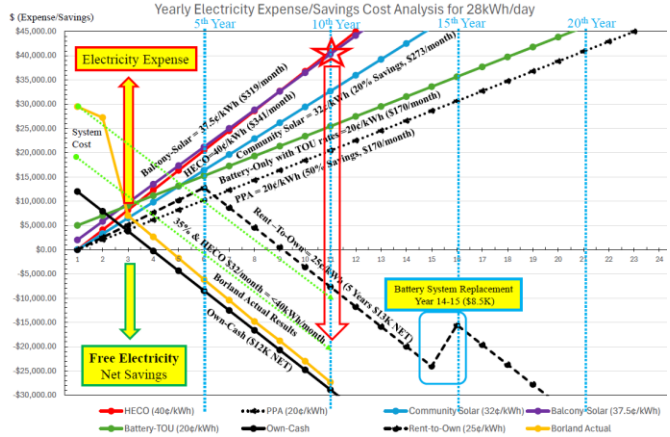

Fig.5: Yearly electricity expense or savings comparison for utility, community solar, Nano-Grid lease or ownership, Balcony-Solar and Battery-Only.

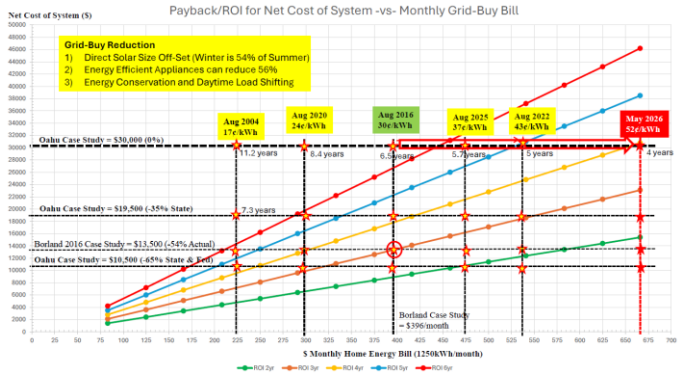

Fig.6: Payback analysis based on final system cost after various tax incentive percentages from 0% up to 65% for various Hawaii electricity rates.

A. *Nano-Grid Lease/PPA*

Fig.5 shows the 10-year cost analysis for Nano-Grid lease/PPA with 50% savings at 20¢/kWh utility bill is $170/month and $20.4K over 10-years. The battery must be properly sized to cover 100% of the overnight energy needs for the minimum $32/month grid connection fee. If not, your total monthly electricity expenses could increase by 15% as shown in the case study in Fig.7. Pre-Solar in 2017, the 12-month average utility grid-buy was 1,291kWh/month or $357/month. The Nano-Grid was installed in 2018 with a monthly lease bill of $185/month. This did not achieve the minimal monthly grid connection fee of $25/month but a $225/month utility bill for a total new monthly cost of electricity of $410/month, a 15% increase or $49K over 10 years. Fig.8 shows proper battery sizing and use of battery as an overnight appliance to meet 100% of the nighttime home loads. The overnight energy usage is <11kWh/night (27%) and battery daily discharge is <15kWh/day. Lease/PPA with a 20+ year contract also means never realizing "Free Electricity of Life".

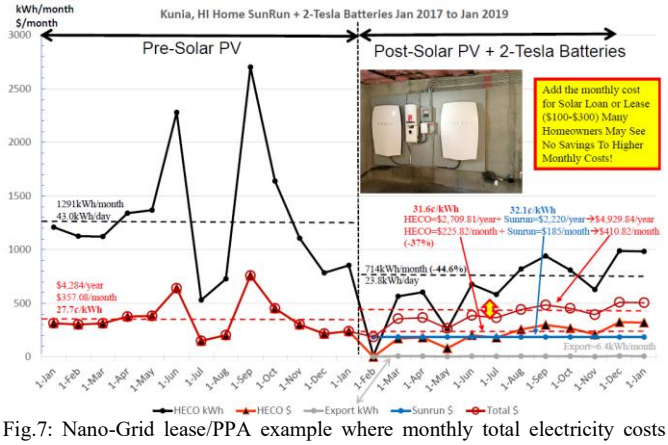

Fig.7: Nano-Grid lease/PPA example where monthly total electricity costs were 15% higher Post-Solar due to undersized battery.

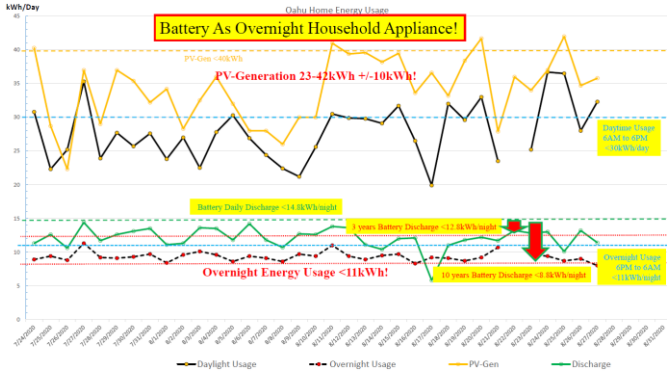

Fig.8: Proper battery sizing for 100% overnight home loads.

B. Balcony-Solar (Portable/Canopy/Patio/Ground Mount Solar Array Designs) Cost Analysis

Recently Balcony-Solar option has received a lot of press on the Mainland based on its success as a Plug-n-Play option in Germany where electricity rates are higher than Hawaii at 43¢/kWh. Back in Sep 2021, I read a South Korean paper using 2-solar panels with a battery installed on an apartment building balcony. It was an extension to "Battery-Only" option if you do not have TOU low daytime rates [10]. I would not recommend using it without a battery because there is no resilience when the sun sets at night or cloudy/rainy days. There is also concern of back feeding power to the grid. My calculations suggest savings would be <6% because balcony solar panels will be mounted near vertical 90-degree tilt angles, on a sunny day will only produce 25% of rooftop solar panels due to limited 1 hour of peak sunlight caused by balcony shading effects reported by Borland and Singh at IEEE-PVSC 2018 irradiance high tilt angle paper shown in Fig.9 [12]. A significant degradation in solar output was observed going from 45 degrees to 90 degrees tilt. Fig.5 shows the cost analysis results for Balcony-Solar, small plug-n-play systems (<1.6kW) saves 6% monthly, add equipment costs of $2K the estimated payback period is 9.5 years for 10-year avoided expense of $555. In the US homes have 240 volts or a 120 volt A line and 120 volt B-line combined for 240 volts. To avoid any back feed and safety concerns since 2023, we turn off the circuit breaker to the wall sockets we are energizing for Off-Grid mode of power and operation as reported in the IEEE Molokai Energy Equity article using 3.6kWh LFP solar-battery generators with ground mount small solar arrays 800-1400W [13].

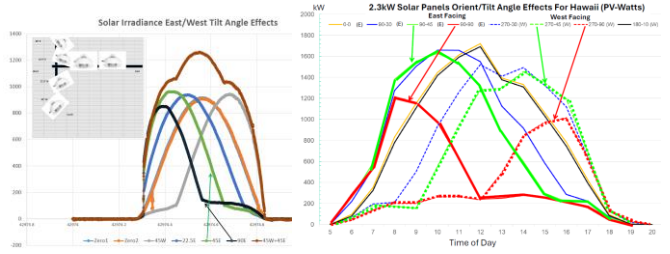

Fig.9: Solar panel tilt angle shading simulations effects from 0 to 90 degrees based on solar irradiance measurements and PVWatts [12].

C. Battery-Only or Battery + Portable-Solar Cost Analysis

Another design we use for Off-Grid Plug-and-Play is to plug the solar battery into the wall outlet and the appliance directly into the battery as an uninterrupted power supply (UPS). During the day the battery is charged by solar or the grid and at night powers the appliances so no back feed. Load shifting high demand loads to daytime and using a battery generator at night allows switching from regular electricity rates (40¢/kWh) to low daytime TOU rates (15¢/kWh) potentially saving another 50% on the utility bill with or without the need for solar panels. But this requires TOU rates with "Battery-Only". Fig. 4 shows the standard versus TOU rates for Hawaii from 2017 to 2026. Lowest daytime TOU rate was 8.6¢/kWh during COVID on 8/2020 and highest evening peak rate of 57.3¢/kWh during Ukraine War on 9/2022 when oil price reached $115/barrel. On average TOU rates are 33-59% lower than standard rates. Fig.10 shows the Off-Grid Plug-n-Play 3.6kWh LFP solar-battery generator with ground mount 1.4kW solar array used to provide resilience to the daily 4 hour home medical dialysis machine treatment and reduced monthly utility bill by 39% [13]. Fig.5 shows 10kWh LFP solar-battery generator costs $5K and with TOU rates without solar reduces electricity rate by 50% and can be used by anyone including high rise condos with no balcony. Payback is <2.5 years and 10-year expense is $25.4K for an avoided expense of $15.5K.


Fig.10: Off-Grid plug-n-play solar-battery system to provide resilience for the daily 4 hour home dialysis medical treatment.

To keep renewable energy equipment costs down, proper sizing of solar and battery is important. The home needs to be energy efficient, energy waste eliminated and energy conservation behavior lifestyle. This requires: step-1, digitization of home energy ecosystem and step-2, use of energy efficient household appliances to reduce electricity demand by up to 56%.

D. Smart IoT Devices For Home Energy Usage Audit

A home energy usage (audit) using Smart IoT devices for energy monitor and control will identify high energy use and any energy waste by separating daytime and nighttime usage for proper solar and overnight battery sizing. It can also give a baseline of your minimum home energy usage, <8kWh/day versus 36kWh/day when no one is at home (vacation mode) as shown in Fig.11, a 4.5x increase. The Pareto Analysis will ID the top 6-8 top home loads for corrective action as shown in Fig.12 with daytime versus nighttime segmentation. Window air conditioner (AC) was 43% tied with water heater followed by kitchen plugs at 5% for 7/4/23. A bad thermostat was the root cause for the random water heater energy spikes up to 24kWh/night and was replaced. Increasing the AC temperature set point from 70°F to 75°F reduced the AC-on/off duty cycle from 100% to 73%, a 27% energy savings

shown in Fig.13. At 78ºF, the AC-on/off duty cycle dropped to 40%. Actual 2-year results for this low-income section-8 renter are shown in Fig.14 from July 2023 to June 2025 reducing utility monthly bill from $250/month (17kWh/day) to $75/month (<5kWh/day), an energy burden reduction of 69% [13]. The kitchen loads (<1.5kWh/day) were transferred to a small Off-Grid Plug-n-Play 3kWh battery generator with 800W ground mount solar array and 300W wind turbine [13].

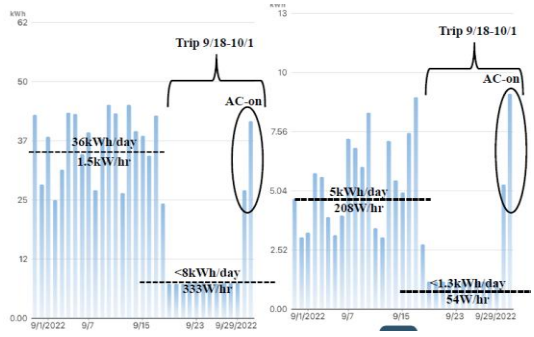

Fig.11: Vacation mode home energy usage, house <8kWh/day.

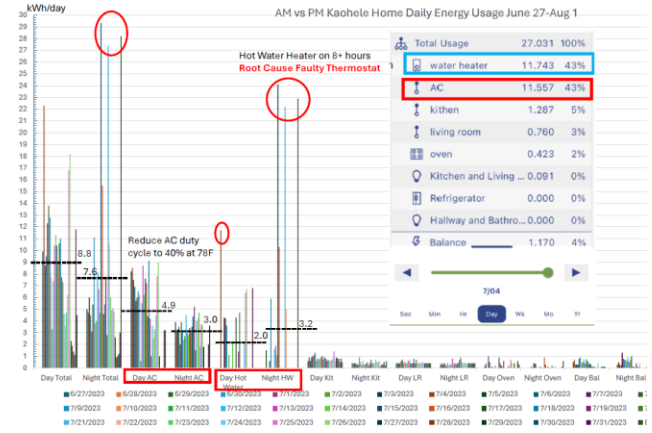

Fig.12: AM vs PM energy usage, random hot water spike shows energy waste.

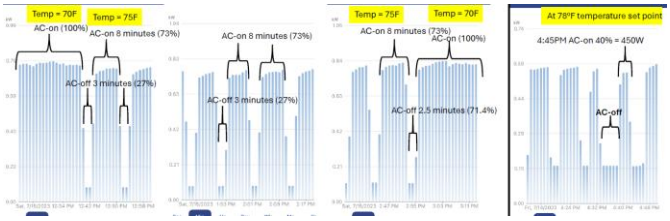

Fig.13: Reducing room AC-on/off duty cycle by increasing temperature step point from 70ºF to 78ºF reduces energy demand by 60%.

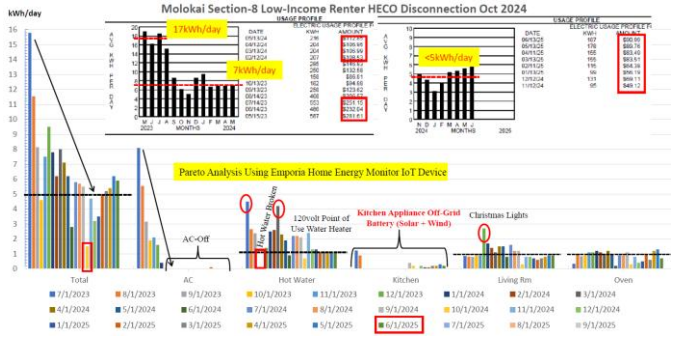

Fig.14: Pareto Analysis of 2 years home energy usage showing 69% savings.

E. Energy Efficienct Household Appliances

Energy efficient appliances such as Energy Star refrigerator/freezer, heat pump water heater, heat pump washer/dryer, induction heating for cooking combined with microwave, AirFryer/toaster oven and using all LED light bulbs can lead to 56% reduction in total energy usage and further savings without adding Solar. Case study examples are: 1) variable speed pool pump saves 81% going from 12kWh/day to 2.3kWh/day (-9.7kWh/day), 2) replacing 45 incandescent light bulbs (60W each) first to compact fluorescent (23W each) in 2017 then LED (8W each) in 2020 saving 87% going from 2.7kWh/day to 360Wh/day (-2.3kWh/day), 3) replace old refrigerator/freezer (4kWh/day) in 3/2022 with Energy Star (1.7kWh/day) saves 76% (-2.3kWh/day), 4) electric water heater going from 12kWh/day (4.5kW power) with solar-thermal water heater (water pump 100W power) in 2016 and then in Jan 2024 adding in series a heat pump water heater (<1.1kW power) for winter water heating 4.3kWh/day saving 64% (-7.7kWh/day) and 5) 240 volt clothes dryer 12.5kWh/week (6kW power) replaced in 7/2024 with a 120 volt heat pump washer/dryer combo 5kWh/week (900W power) saving 60% (-7.5kWh/week) as shown in Fig.15 showing 4 years of home energy monitoring and reduction in household appliance load with energy efficiency improvements. In total, the daily electricity usage was reduced by 72% (-23.4kWh/day) going from 32.5kWh/day to 9.1kWh/day. Using Hawaii electricity prices at 40¢/kWh, that saves $3,416/year or $34,160 over 10-years just from energy efficiency. Adding "Battery-Only" with daytime TOU rates increases savings to $4,246/year and $42,460 over 10-years.

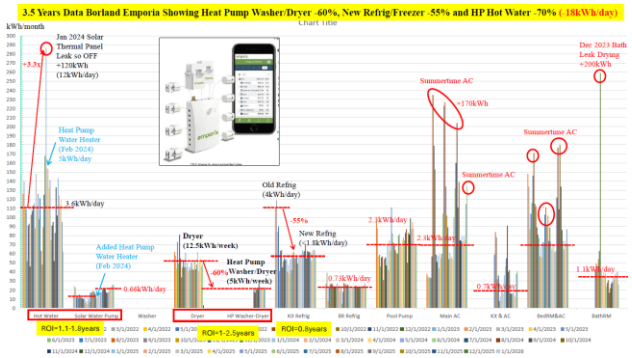

Fig.15: Emporia home energy usage audit showing changes due to energy efficient appliances from 2022 to 2026.

The 10-year operating costs for a 65-gallon electric water heater is $600 equipment cost and daily energy cost of 5.5kWh/day at 40¢/kWh ($2.20/day) is $8,630. Hawaii Energy offers $500 cash rebate for a 50-gallon heat pump water heater plus the 30% federal tax incentives, reduces the equipment costs from $1699 to $839 and daily energy use of 1.6kWh/day costs $0.64/day for a payback of 10 months and 10-year total costs of $3,175 (savings of $5,455). A Solar-Thermal 80-gallon hot water system gets a Hawaii Energy rebate up to $1,500 plus Hawaii State and Federal credits for a final equipment cost of $1,861, daily energy for the water pump is 600Wh/day ($0.24/day), a payback of 1.4 years and 10-year total cost of $2,741 (savings of $5,889). Fig.16 shows the detailed daily and hourly results when switching from the

electric water heater to the heat pump water heater in Jan 2024. Daily energy usage dropped from 12kWh/day to <5kWh/day with a savings of 58%. When the temperature is set to 115ºF during the day and overnight, the heat pump power level is <500W but when the temperature is increased at 3PM to 135ºF for bath, the power level jumps to 1.1kW. Fig.17 shows the 240-volt electric clothes dryer power heating level of 5.9kW compared to a 120-volt ventless heat pump washer/dryer combo with peak power heating level of only 900W from July 2024. You can see the 5.9kW power on/off duty cycle and uses 6.3kWh/cycle compared to the heat pump with constant power between 500-900W and uses 2.5kWh/cycle, an energy savings of 60%. No moving clothes between washer and dryer.

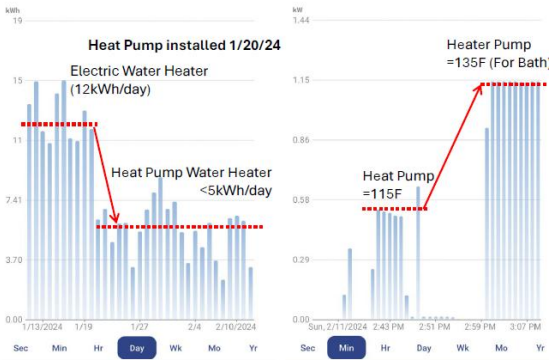

Fig.16: Heat pump energy usagbe profile for a family that takes baths at 135ºF.

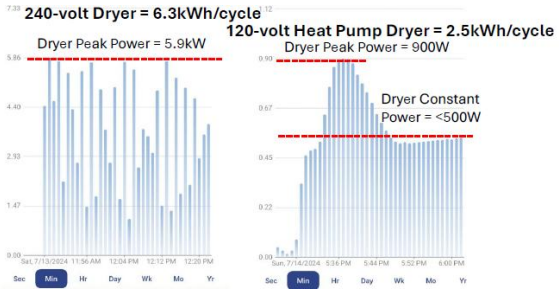

Fig.17: Standard 240 volt clothes dryer peak power of 5.9kW compared to 120 volt heat pump washer/dryer combo with peak power of 900W.

III. SUMMARY

In summary, we evaluated the various Solar for All options based on 10-year economic benefit for Hawaii's high electricity rates of >40¢/kWh and avoided expense/savings for low-income families as summarized in Fig.18. Nano-Grid Solar + Battery ownership and Rent-to-Own options will lower the monthly utility bill for the "Have Nots" by 50-90% and realize Energy Equity. Over a 10-year period, savings of $29K with Free Electricity for Life after payback of 2.5 years. In Hawaii with low daytime TOU rates, Battery-Only allows renters, apartment and high rise condo dwellers without balconies to benefit with >50% cost savings and provide resilience and safety to power outages with home lifesaving medical devices.

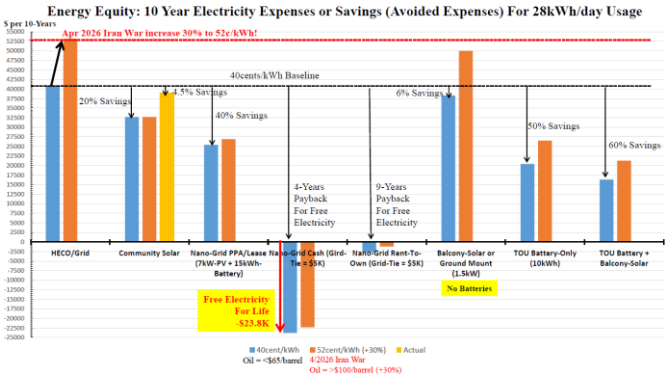

Fig.18: Summary of 10-year electricity avoided expense or savings cost analysis.

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