School of Electrical Engineering Computing and Mathematical Sciences

Optimal Sizing and Economic Analysis of Community Battery Systems Considering Sensitivity and Uncertainty Factors

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This thesis report is presented for the Degree of
Master of Philosophy
Of
Curtin University

September 2024

DECLARATION

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

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Human Ethics (For projects involving human participants/tissue, etc) The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number #........................

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Animal Ethics (For projects involving animal use) The research presented and reported in this thesis was conducted in compliance with the National Health and Medical Research Council Australian code for the care and use of animals for scientific purposes 8th edition (2013). The proposed research study received animal ethics approval from the Curtin University Animal Ethics Committee, Approval Number #........................

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Abstract

Efficient sizing and economic analysis of community battery systems is crucial for enhancing energy efficiency and sustainability in rooftop PV panel-rich communities. This thesis proposes a comprehensive model that integrates key technical and economic factors to optimise the size and operation of the prosumers-owned battery, maximizing their financial returns over the life span of the battery. Sensitivity and uncertainty analyses were also conducted on a number of factors that are constantly changing over the years such as per unit cost of the battery, interest rate, annual degradation rate. Monte Carlo simulations were utilized to replicate the unpredictable PV generations and the volatility of house load demands. The developed model is evaluated under three scenarios: a shared community battery for all houses, individual batteries for each house, and a combined system with an additional large load. Particle Swarm Optimisation (PSO) is utilised to maximize the formulated objective function subject to the considered constraints. The findings indicate that integrating community battery offered a substantial economic advantage than individual home-batteries. Additional revenue stream of incorporating larger consumers looking for reducing carbon footprint (eg. commercial) returned a further augmented net present value NPV. The influence of different tariff structures is also assessed and concluded the critical peak pricing (CPP) to be the most prolific. The outcomes offer valuable insights for policymakers and stakeholders in the energy sector to facilitate a more sustainable future.

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Nomenclature

A. Abbreviations

ADR	Annual Degradation Rate
BESS	Battery Energy Storage System
CB	Community Battery
CBS	Community Battery Systems
CES	Community Energy Storage
COE	Cost of Electricity
CPP	Critical Peak Pricing
CV	Coefficient of Variation
FiT	Feed in Tariff
LUoS	Local Use of Service
NPV	Net Present Value
NZE	Net-Zero Energy
PDF	Probability Density Function
PSO	Particle Swarm Optimization
PV	Photovoltaic
P2G	Peer to Grid
P2P	Peer to Peer
SA	Sensitivity Analysis
SOC	State of charge
TCOE	Total Cost of Electricity
TOU	Time-Of-Use
UA	Uncertainty Analysis

B. Parameters

ACC	Number of full charge and discharge cycles the battery undergoes in a year
ADR	Rate at which the battery's capacity degrades each year
ASL	Amount of energy lost while the battery is in standby mode
$\mathrm{A}_{\mathrm{k}}^{\mathrm{h}}$	Binary control parameter
B_{life}	Operational lifespan of the battery
$\mathrm{Cost}_{\mathrm{IC}}$	Battery installation’s cost
$\mathrm{Cost}_{\mathrm{k}}$	Cost of energy per kWh depending on time of the day
$Cost_{LUoS}$	Cost per kWh for using the local network
Cost_{pu}	Battery per unit cost
CPC	Maintenance cost accounted for each full charge and discharge cycle
c1, c2	Acceleration coefficients for PSO
Eff	Roundtrip efficiency
E_{c}	Cost per tonne of emissions
E_{pu}	Per kg of Co2 emission in 1 kWh
I_{r}	Interest Rate for NPV calculation
n	Number of households in the community
SOC_{min}	Minimum SOC of the battery
SOC_{max}	Maximum SOC of the battery
$\mathrm{TP}_{\mathrm{btl}}$	Total unit power supplied from battery to house load in a year
T_{struct}	The Tariff’s structure
T_1, T_2	Start and end times of Peak hours
T_3, T_4	Start and end times of first shoulder hours
T_5, T_6	Start and end times of second shoulder hours
T_7, T_8	Start and end times of off-Peak hours
w	Inertia weight for PSO
σ	Standard Deviation
μ	Mean Value
β_{ζ}	Selling rate per kWh (To grid or large load)
β_{LL}	Large load rate per kWh

β_{FiT}	FiT rate per kWh
λ^{sell}	Selling rate of power to the CB battery per kWh
λ^{buy}	Buying rate of power from the CB per kWh

C. Variables

C_i	Cumulative energy contribution by house i
$\mathrm{Cost}_{Battery}$	Total cost of the battery
$Cost_{Degradation}^{yr}$	Annual degradation associated losses
$Cost_{Operation}^{yr}$	Annual maintenance associated losses
E_i	Energy contribution by house i
$E_{surplus}$	Total combined surplus energy in kWh
$G_i^s(\mathrm{x},\mathrm{h})$	Grid supply power of house i at a given hour h on day x
GBEST	Global best position among all particles
NPV	NPV for the Prosumers in AUD
PBEST	Personal best position of the i^{th} particle
$P_{bal-CB}^{(h)}$	Total balanced power
P_i^{B2H}	Power from battery to house i
P_i^{H2B}	Power from house i to battery
PV_i^{Gen}	PV generation in kW for house i
P_i^{Load}	Load power in kW for house i
$P_{TCB}^{(h)}$	Total power transactions
PV_i^{Gen}	PV generation in kW for house i
PV_{i*}^{Gen}	Adjusted PV Generation for Uncertainty Analysis simulations
$Save_{emission}^{yr}$	Total cost saved in emission reductions
$\mathrm{Size}_{\mathrm{CB}}$	Battery size in kWh
$\mathrm{TCOE}_{\mathrm{benefit}}$	Total financial benefits as a result of CBS's integration
TCOE_{CB}	Combined total COE after CBS integration
$\mathrm{TCOE}_{\mathrm{intial}}$	Combined total COE before CBS integration
V_i	Random variation drawn from normal distribution and added to base PV values
v_i^t	The velocity of the i^{th} particle
x_i^t	The position of the i^{th} particle
$\mathrm{yearly}_{\mathrm{cashflow}}$	Annual cash flow
Π_{ζ}	Cost benefit from selling surplus energy

Chapter 1: Introduction

1.1 BACKGROUND

Recently, the global shift towards green energy has led to a significant rise in the adoption of photovoltaic (PV) rooftop panels. Australia, for instance, has witnessed a significant growth from approximately 178 MW in 2010 to 34,200 MW in 2023, of which the majority of installations are below 9kW and typically residential rooftops [1].

The driving force for such change is a result of environmental concerns as well as cost reduction seeking. While the proliferation of PV panels is certainly favorable and advantageous, it still presents distinctive challenges, particularly when a large percentage of households in a community decide upon installing PV systems. Such complications entail managing the irregularity and intermittency of solar generation, maintaining an energy supply and demand balance, and ensuring equitable and impartial access to the benefits of clean energy. A revolutionary solution, community batteries offer a new way for communities to manage their energy requirements. Community batteries have the ability to store, and discharge during periods of high demand when required, surplus PV energy, thereby enhancing energy utilization and delivering monetary and fiscal benefits to communities [2-4]

Community battery systems (CBS) offer several benefits, such as better energy utilization, grid stability enhancement, and energy expenses reduction. These systems can aggregate the surplus photovoltaic (PV) energy generated by individual households and store it in a central battery. The stored energy can then be distributed as required to re-duce grid dependence and lower the energy bills. Nevertheless, despite the potential benefits, several economic and technical variables and constraints make the optimization of community battery's capacity functionality essential yet complex.

1.2 PROBLEM STATEMENT

Optimizing CBS encompasses several interlinked factors. Components such as unit battery costs, degradation rates, tariff structures and configurations, and solar power generation and fluctuation. Current literature primarily centers the focus on particular elements of the CBS like economic evaluation [2], environmental and ecological impacts [5, 6], or different optimization techniques [7, 8], often in isolation. The segmented models lack thorough comprehending of the parameter's influence on the overall performance of CBS such as effectiveness and economic viability. In addition, there is less emphasis in the literature on various tariff configurations and their potential impacts on the solution. This study aims to establish a complete framework for optimizing CBs and to contribute to the broader objectives of promoting environmental sustainability and enhancing green energy efficiency.

Additionally, this thesis delineates how the integration of such technologies assists the communities in lowering their carbon footprint, promote self-sufficiency and energy resilience, and encourage environmental sustainability. Furthermore, it highlights the value of prosumers' collaboration with local governmental authorities and energy providers to maximize the community battery initiatives' financial, technical, and environ-mental benefits. The primary objective of this research is to improve solar energy utilization, maximize potential monetary benefits, and foster the adoption of eco-friendly energy systems in community settings.

1.3 RESEARCH SCOPE

The scope of this study entails the development of a holistic methodology to optimize the size of community batteries using historical data in a high PV-penetrated community, the simulation of the proposed system to assess its viability, and the evaluation of the influential levels that key parameters have on the results. The research concentrates on multiple domains to present a thorough analysis of the economic, operational, and environmental facets of CBS.

First, a mathematical model incorporating critical factors such as: Battery initial capital costs, degradation rates, PV solar generations, and diverse tariff structures, is developed to optimize the community owned CBS's capacity and operation, maximizing the financial benefits for the prosumers. The research then, through the simulation of different scenarios, evaluates the economic feasibility of the proposed approach over a 10-year period, which is the average operational lifespan of commercial lithium-ion batteries and standard economic evaluation horizons in the literature. Thereby, ensuring the analysis covers most of the community battery's practical life, while accounting for the impact of degradation.

Second, a comprehensive sensitivity analysis on key parameters is conducted to assess the influence level each variable possesses on the optimization outcomes. The assessed variables are: The cost per unit of battery, annual degradation rate (ADR), and interest rate (IR). Stochastic Monte Carlo simulations are then utilized to appropriately consider solar energy's randomness, by systematically adjusting the power within practical ranges, in the economic and technical evaluations of the uncertainty analysis.

Furthermore, the study compares the performance of the proposed methodology under different tariff pricing frameworks to evaluate the efficiency of CBS and make recommendations of the most favorable from financial perspective to encourage the adoption of this technology. This includes structures such as: Block tariff, time-of-use (TOU), critical peak pricing (CPP), and seasonal tariffs.

The presented extensive and holistic approach is believed to ensure the tackling of complex aspects and addresses the multifaceted nature of community battery optimization, as well as offering useful insights and practical solution to promote sustainable energy practices.

1.4 THESIS STRUCTURE

This thesis is structured into five Chapters, each of which addresses various areas of the research conducted to provide a thorough analysis of the optimization process proposed for community battery and PV integrated systems. Chapter 2 reviews the existing literature and studies on PV systems, energy storage solutions, and community battery systems. Chapter 3 outlines the overview of the research approach, mathematical modelling and formulations. Chapter 4 presents simulation outcomes for each scenario. Chapter 5 concludes the thesis and presents suggestions for future works.

1.5 LIST OF PUBLICATIONS

This thesis has led to the publication of 1 peer-reviewed journal article and 1 conference paper. The details of these publications are provided below.

- Ragab Z, Pashajavid E, Rajakaruna S. Optimal Sizing and Economic Analysis of Community Battery Systems Considering Sensitivity and Uncertainty Factors. Energies. 2024; 17(18):4727.
- Ragab Z, Pashajavid E, Rajakaruna S., Community Battery System Sizing To Maximize Financial Returns to the Prosumers in PV-Rich Neighborhood, i-COSTE, Murdoch University, 2024.

Chapter 2: Literature review

Energy storage systems (ESS) are vital components to maximally benefit from renewable energy sources due to their intermittent supply. Due to their high ability of storing and releasing excess energy generated, lithium-ion, lead-acid, and flow batteries are common storage examples of such green energy applications to ensure reliability and enhance grid stability [9]. Lithium-ion batteries are frequently preferred for their high energy density and efficiency [10].

From the utility grid perspective, CBs facilitate energy supply at high demand periods, reducing the reliance on the grid which improves stability due to lower sudden peaks of communal load demands. While for the local community, the combined excess of PV energy generation by the participating prosumers can be utilized more effectively to meet the local demand and reduce electricity bills. Therefore, CBSs provide potential benefits to both the utility, through grid stability, and the prosumers, through monetary benefits and energy resilience [7].

CES was first developed to concurrently perform demand load shifting as well as PV energy time-shifting through retail tariffs with variable and changing pricing blocks [3]. Two market designs, taking into account the recent emergence of several local or peer-to-peer (P2P) energy trading networks, specifically addressed the role of electricity storage [11]. Background in the framework of Germany's energy transition, there is an inclining number of residential households utilizing their own solar system to partially off-set their power usage. These systems bring combined economic benefits such as reduced energy costs, since the community shifts some of the energy consumption from grid to stored self-generated PV energy, as well as an improved return on investment (ROI) and potential revenue by selling any excess energy. In addition to yielding financial rewards, CBSs assist in the reduction of carbon emissions and footprint particularly when paired with PV systems. This facilitates the shift towards a more sustainable future [12].

2.1 OWNERSHIP STRUCTURES

The ownership of the CBS plays a major role in its project's economics. To address potential risks, high prices, and other adoption constraints, a transition from ownership models to access and collaborative business models with different actors has been proposed in [13, 14]. Research has already indicated that user-owned BESS, including residual sharing and storage sharing, yields a higher net present value compared to other BESS ownership structures [15]. The authors examined two distinct ownership schemes for optimal BESS sizing; One structure where the energy service provider ESP owned the BESS, and the other one where the users owned the shared community battery. Research has shown that although ESP-owned structure lowered the prosumers energy expenses without having to invest in the capital initial cost of the battery, the community owned structure demonstrated higher net present value NPV. This thesis, however, did not examine the impacts of various tariff-structures nor has presented the most influential parameters on the optimization system and economic benefits.

Nevertheless, the decline of on-grid electricity prices caused by the wide-spread adoption of PV power generation has made it crucial to avoid excessively large battery sizes when using community energy regulation. It is, therefore, also necessary to rationally optimize the battery capacity [16, 17]. To address a lack of energy management strategies that tackle different possible interactions among community-clustered solar plus battery prosumers, a study [18] proposed an optimal EMS approach. The system involves the participation of five solar plus battery prosumers in the energy community in the aggregated aFRRR-market. The main objective of the study was to minimize the total costs of ownership for each prosumer and results were validated through different scenarios' simulations. The proposed system enabled a decrease in levelized cost of energy LCOE for all members of the community compared to the base-case scenario.

2.2 APPLICATIONS

ESSs are widely used in many applications. One of which is peak demand reduction from individual household level [19, 20], to large-scale buildings [21, 22]. The authors in [19] presented a sizing model for peak load shaving. The proposed method incorporated keeping the demand below a predetermined threshold. A MO optimisation problem was developed to overlook peak demand charge and focus primarily on the cost of energy with the objective of minimising both the cost of energy and the peak load [20]. Similar research was published in [21]. In this research, a battery algorithm to reduce the peak load demand was suggested. [23, 24] Also took into account peak demand charge, however, the authors assumed a flawless one-month forecast, which given the significant degree of uncertainty is not a comprehensive approach.

CBS have also been used in a number of other applications. A number of research have studied the utilization of leveraging flexibility on the demand, an integral attribute of smart grid advancements [25]. Modern prosumers can modify their load demand in order to shift their consumption to off-peak times using a home energy management system. Several price-responsive strategies for prosumers have been posed in order to predict their response in a highly dynamic electricity pricing environment [26]. The authors of [27-29] examined a nonlinear demand response application that gains prosumers' satisfaction for their electricity consumption.

2.3 OPTIMISATION TECHNIQUES

The optimization of CBSs has been investigated in several studies. Abdulla et al. [30] proposed an optimized sizing approach that determines the most efficient size and management of the CBSs that results in the maximum economic benefits. Another study, [31], emphasized how economic consideration alone will not be sufficient in the absence of environmental factors. The authors illustrated the necessity for methodologies to consider both financial and ecological factors.

A novel approach combining energy disaggregation, as proposed in [11], to distinguish net load from generated PV power and battery charging and discharging power. An energy management optimization system was implemented and integrated in a community microgrid system. The cost function included battery degradation costs as well as dynamic penalty that accounts for the actual operational costs [12]. Ansari et al. [32], conducted economic analysis to determine the optimal size and operation method of an energy storage system in a PV-grid integrated network.

In 2023, a comprehensive study was conducted to analyse and quantify the ad-vantages of CBs, particularly in a setting of collaboration between a dis-tributed system operator (DSO) and energy community [33]. A linear optimization model was developed to take power flow constraints and battery's degradation factor into account, which then highlighted the influence of disregarding degradation models. The findings concluded much less violations on the voltage limits in the absence of this factor, underscoring the essence of holistic modelling in such applications. The authors proceeded by performing a sensitivity analysis to identify the most influential parameters on the voltage violations. Economic evaluation, however, was excluded from the research.

Zhang et al. [34] performed a comparative analysis of multiple typical storage sharing schemes, which were developed based on different installation structures and sharing techniques. A load optimization model was established to reduce the total power cost of industrial parks, based on the features of each scheme using real historical data. Considering P2G and P2P energy exchange scenarios, [35], Yaldiz et al. evaluate the financial contribution of each in an optimized PV-BESS integrated system. The aim of this system is to maximize the return of users and net profit after cost. The results demonstrated that utilizing P2P energy trading schemes leads to significant advantages for the consumers that transition into prosumers in the proposed framework.

A multi-objective optimization methodology was developed and applied to optimize the battery size and evaluate the impactful parameters on the optimization system. This, however, only considered one tariff pricing scheme [36]. Another techno-enviro-economic study on community battery storage systems [37], investigated and compared the ROI and payback on two tariff structures. The results concluded that while flat tariff maximizes PV energy consumption, TOU tariff allows greater cost reductions. Both structures could pay back total manufacturing carbon emissions within 8 years. The study, however, did not include any other structures. According to both [36, 37], recent research lacks holistic analysis on different tariff pricing on community battery projects. Prior research has illustrated the benefits of including BESSs [38, 39]. Furthermore, extensive research on optimal battery sizing has been done [40, 41], as well as battery performance and life-cycle enhancements [15].

The authors of [42] presented an electricity bill reduction technology through an optimised planning of the microgrid. The innovative approach leverages probability estimates of peak loads, outlining microgrids ability to minimise coincident and non-coincident peak charges, thereby reducing peak contributions and lowering the electricity bills. A Model Predictive Control (MPC) approach was presented in [43] to maximize the energy costs in a residential neighbourhood through the utilisation of a community shared battery with the motive of encouraging investments.

The study compared two simulated scenarios with varying control horizons. The MPC model, through its predictive management scheme, demonstrated up to $67.91 savings per month. Potential impacts of neighbourhood batteries and virtual power plants in comparison to coordinated and uncoordinated household batteries have been investigated in [44]. The findings illustrated similarities between neighbourhood batteries and virtual power plants in terms of reducing the average peak demand by 82% more than household batteries and improving grid stability.

Cholette et al. [45], developed an approximate dynamic programming (ADP) approach to optimise the battery’s dispatch to reduce the electricity bill for the end users. This approach was applied to extracted data from an Australian community and yielded 25% reduction in monthly average peak demand, accounting to 8% reduction in electricity bills. Financial and energetic benefits of a centrally controlled community battery system were analysed and investigated in [46]. This paper concluded that community operation served larger battery and converters sizes, allowing greater PV utilisation, lower electricity bills, and reduced grid reliance. Apribowo et al. [47], evaluated the economic feasibility of using second-life battery as a community shared storage. The results demonstrated an improved reliability by reducing PV curtailment costs by 66%, as well as a reduction of 13.63% in battery investment costs.

2.4 RESEARCH GAP

An extensive review of the current existing literature highlights the growing attention on community battery systems, in particular within the framework of multi-household environments and communities. The review, nonetheless, uncovers notable gaps that this research aims to address. Some of which are summarized in the Table 1:

Table 1: Summary comparison between recent studies and this research

Research Paper	Community Battery Systems	Individual Battery Systems	Optimization Techniques	Economic Analysis	Sensitivity & Risk Analyses	Exploration of tariff structures
[48]	✓	✗	Linear Programming	✓	✗✗	✗
[49]	✗	✓	Linear Programming	✓	✗✗	✗
[50]	✗	✓	MO Optimization	✓	✓✗	✓
[51]	✓	✓	Linear Programming	✓	✗✗	✗
[52]	✗	✓	✗	✗	✗✓	✗
[53]	✓	✓	Linear Programming	✓	✗✗	✗
[54]	✓	✓	Linear Programming	✓	✗	✗
[55]	✗	✓	Stochastic Optimization	✓	✗✓	✗
This thesis	✓	✓	PSO	✓	✓✓	✓

Table 1 highlights a number of research papers which offer a contextual background for the presented study of CBS optimisation under high PV penetration applications. For instance, Hossain et al. [48] investigate the economic optimization of CBS in microgrids, aligning with this thesis's objective of enhancing CBS optimisation but in absence of sensitivity, risk, and tariff analyses. Heinisch et al. [49], contributed insights to the impact of different ownerships between community-owned and individually-owned batteries. Focusing on MO optimisation for grid connected PV-BESS under TOU tariff structure provides a strong base for financial impacts tariff structures can impose [50]. The authors of [51] developed a model for P2P energy trading in a community-owned system. Another P2P energy management strategy in CBS was introduced in [53]. Both [49] ,[50, 53] have not explored the financial influence of tariff structures on the models. Solar generation's associated uncertainties were discussed in [52] and [55]. However, [52] lacked the economic evaluation and the focus in [55] on large customers diverges from this thesis's CBS focus, presenting opportunities for complementary insights. The tabulated papers helped determine gaps that this thesis intends to bridge, particularly holistic modelling, tariff structures impacts, and sensitivity analyses.

Despite the significant advancements and substantial contributions in the literature in terms of community battery systems integration and optimization, there are still a number of gaps, as presented in the preceding chapter, that this research aims to address. As the authors in [33] has highlighted that the inclusion of degradation factor has greatly influenced the results, therefore, this research intends to formulate a holistic approach taking into account various parameters to maximize the monetary income for the community in a community-owned structure.

With that, not only simulations are run using historical data as a case study to evaluate the suggested methodology, but also extensive risk and uncertainty analyses are performed to evaluate the influential impact of key parameters on the results. Montecarlo simulations are utilized to generate and iterate the unpredictable nature of solar power generation. Nevertheless, as there is a major gap in assessing the impact of different tariff pricings and structures, additional investigations are made to provide stakeholders and policy makers with suggestions to aid with the encouragement of community battery integration, resulting in ecological sustainability.

Chapter 3: Development of Mathematical Modelling

As the focus of the present work is to optimize the community-owned CBS in order to yield the most economic benefits to the prosumers, where PV integration is high, the approach involves holistic modelling to accurately account for all the potential associated costs. This includes considering the capital cost of the battery being owned and implemented by the prosumers, potential expenditures with degradation, tariff rates, savings from monetized carbon emission reductions, and energy trading among households, utility grid, and community battery. Figure 1 represents a community composed of n houses with rooftop PV systems and a community battery.

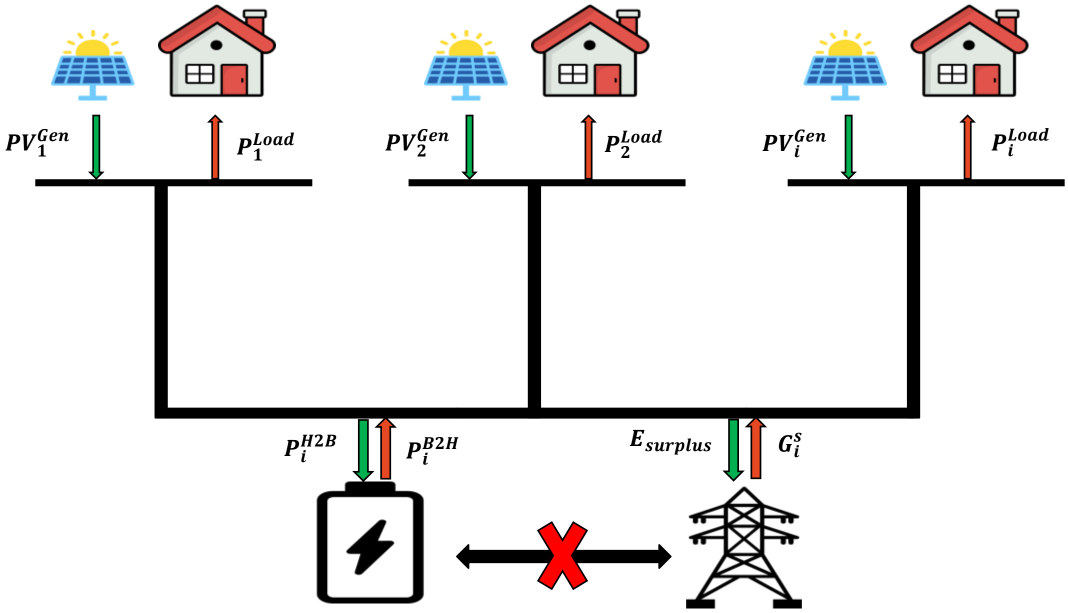

Figure 1: Grid, PV, and Community Battery

Allocation of energy flow from the community battery is primarily directed to supply the involved households during peak demand hours, while the second priority is shoulder hours, depending on tariff structures. The initial consideration will be TOU due to the diversity and widespread use, followed by simulations on other existing structures. The financial dynamics of this scheme are influenced by the discrete rates at which energy trading transactions among the three-elemental system (Grid, CBS, and PVs) occur.

3.1 TIME-OF-USE PRICING

The determination of energy costs supplied by the distribution firm is based on the utilization of available 24-hour data. The present computation integrates TOU pricing, which includes peak load demand, shoulder load demand, and off-peak load demand. The temporal divisions for different categories of electricity use, together with the related kilowatt-hour rates, are determined based on schedules given by utility companies and the associated tariff structures. A generalized model is presented in the following Quasi-code.

```
Hours h= 1,2,3,4…….24
$A_1^h = 1, A_2^h = 0, A_3^h = 0$   $(T_1 < h < T_2)$
$A_1^h = 0, A_2^h = 1, A_3^h = 0$   $((T_3 < h < T_4) \mid\mid (T_5 < h < T_6))$
$A_1^h = 0, A_2^h = 0, A_3^h = 1$   $(T_7 < h \leq T_8)$
```

where $T_1 \rightarrow T_8$ account for the timely schedules of the peak, shoulder, and off-peak hours in a TOU setting. A_1^h, A_2^h, A_3^h: Binary control parameter for hourly cost calculation

3.2 NETWORK COSTS

Often neglected in research, costs for transmission, distribution, and local transport of energy pertain to the expenses affiliated with conveying the energy when integrating community battery in a certain locality. These costs are referred to as Network costs. In Australia, the cost of energy per kWh comprises two distinct elements: the cost of the energy itself and the cost of transferring it. The cost of transporting energy locally within a community is relatively cheaper than wider distribution network according to the National Energy Rules (NER) and is referred to as the Local Use of Service (LUoS). Local energy exchange includes peer-to-peer (P2P) energy exchange between consumers as well as energy exchange to and from the common CES [56, 57].

And although minor, cumulative effect can be impactful and therefore is added in this research for more accuracy. The value per kWh will depend on the network provider and is applied on every charge and discharge of the battery [58].

3.3 PROBLEM FORMULATION

The combined total cost of electricity (COE) for a community of n households and a given tariff structure before and after CBS integration is modelled in (1) & (2) respectively. The calculations are done over the life span of the battery B_{life} in order to determine the community savings after integrating the battery.

$$\mathrm{TCOE_{intial}} = \sum_{y=1}^{B_{life}} \sum_{x=1}^{365} \sum_{h=1}^{24} \sum_{i=1}^{n} \sum_{k=1}^{T_{struct}} \mathrm{A_k^h} * \mathrm{Cost_k} * G_i^s(\mathrm{x,h}) \tag{1}$$

$$\begin{aligned}\mathrm{TCOE}_{CB} = \sum_{y=1}^{B_{life}} \sum_{x=1}^{365} \sum_{h=1}^{24} \sum_{i=1}^{n} \sum_{k=1}^{T_{struct}} (\mathrm{A_k^h} * \mathrm{Cost_k} * G_i^s(\mathrm{x,h})) - (\lambda^{sell} \\ - Cost_{LUoS}) * P_i^{H2B}(\mathrm{x,h}) + (\lambda^{buy} + Cost_{LUoS}) \\ * P_i^{B2H}(\mathrm{i,h})\end{aligned} \tag{2}$$

where $\mathrm{TCOE_{intial}}$: combined total COE for n households before CBS integration, $\mathrm{Cost_k}$: per kWh energy cost based on the tariff's pricing scheme at time h for 24 hours of the day, $\mathrm{A_k^h}$: binary control parameter, T_{struct} is the tariff's combination, G_i^s: grid supply power to house i. TCOE_{CB}: combined total COE for n households before CBS integration, λ^{sell}: selling rate of power to community battery, λ^{buy}: buying rate of power from community battery, P^{H2B}: power from house i to battery, P^{B2H}: power from battery to house i, $Cost_{LUoS}$ is the cost per kWh using the local network (LUoS).

The total combined surplus power at times where PV generation exceeds the load demand while the community battery is unable to be further charged due to constraints and limitations set in section 3.7 is calculated in (3). This power is fed to the grid to benefit from the Feed-in-Tariff (FiT) as in (4), subsequently calculating the total financial benefits as a result of CBS's integration in (5).

$$E_{surplus} = \sum_{y=1}^{B_{life}} \sum_{x=1}^{365} \sum_{h=1}^{24} \sum_{i=1}^{n} PV_i^{Gen}(x,h) - (P_i^{Load}(x,h) + P_i^{H2B}(x,h)) \tag{3}$$

$$\Pi_\zeta = \beta_\zeta * E_{surplus} \tag{4}$$

$$\mathrm{TCOE_{benefit}} = \mathrm{TCOE_{intial}} - (\mathrm{TCOE}_{CB} + \Pi_\zeta) \tag{5}$$

where $E_{surplus}$: total combined surplus energy in kWh, PV^{Gen}: PV generation in kW, P^{Load}: Load power in kW, Π_ζ: cost benefit from selling surplus energy, β_ζ: selling cost per kWh while ζ differentiates between FiT and large load (LL) rate for different cases, $\mathrm{TCOE_{benefit}}$: total financial benefits as a result of CBS's integration.

3.4 BATTERY COSTS

Comprised of three primary elements, the cost of the battery incorporates: Installation cost of the battery, degradation associated losses, and ongoing operation & maintenance costs of the battery presented in (6)-(8). One of the most dominant factors of which is the battery installation costs, consisting of the costly price of the battery, the labour required for installing, and the necessary infrastructure. Operation costs in (7) account for potential lost revenue due to standby periods of the battery as well as maintenance cost accounted for each full charge and discharge cycle.

Degradation of the battery gradually decreases its capacity; thus, the associated battery degradation cost is directly proportional to how much energy degrades over the lifetime of the battery. As the proposed model prioritizes PV supply to the load and CB over the grid, the monetized degradation cost in (8) presents the potentially lost costs that could have been sold to the grid [59-61]:

$$\mathrm{Cost}_{Battery} = \left(\mathrm{Cost}_{pu} * \mathrm{Size}_{\mathrm{CB}} + \mathrm{Cost}_{\mathrm{IC}}\right) \tag{6}$$

$$Cost_{Operation}^{yr} = (\mathrm{ACC} * \mathrm{CPC}) + (\mathrm{ASL} * \beta_{FiT}) \tag{7}$$

$$Cost_{Degradation}^{yr} = \mathrm{Size}_{\mathrm{CB}} * \mathrm{ADR} * \beta_{FiT} \tag{8}$$

where: $Cost_{pu}$: battery per unit cost, $Cost_{IC}$: battery installation's cost, ADR: rate at which the battery's capacity degrades each year, $Cost_{Degradation}^{yr}$: annual degradation associated losses, $Cost_{Operation}^{yr}$: annual maintenance and operation associated losses, Annual Cycle Count (ACC): number of full charge and discharge cycles the battery undergoes in a year, Cost per Cycle (CPC): maintenance cost accounted for each full charge and discharge cycle, Annual Standby Losses (ASL): amount of energy lost while the battery is in standby mode, $\mathrm{Size}_{\mathrm{CB}}$: Battery size in kWh.

3.5 SAVINGS IN EMISSIONS COST

As this work seeks to illustrate not only economic benefits but also environmental encouragement, evaluating the cost savings in carbon emissions derived from the implementation of the community battery system is instrumental. The following equation quantifies monetary benefits associated with these reductions, and is supported by analyses reports done by the International Energy Agency (IEA) [62]. Therefore, the addition of this factor allows for a comprehensive evaluation of both sustainability and cost-effectiveness of CBSs.

$$Save_{emission}^{yr} = \mathrm{TP}_{\mathrm{btl}} * \mathrm{E}_{\mathrm{c}} * \mathrm{E}_{\mathrm{pu}} * 0.001 \tag{9}$$

where $Save_{emisson}$: total cost saved in emission, TP_{btl}: total unit power supplied from battery to house load in a year, E_c: cost per tonne of emissions, E_{pu}: per kg of Co2 emission in 1 kWh.

3.6 PARTICLE SWARM OPTIMISATION

In complex systems with multiple parameters and frequently changing inversely interlinked variables, optimisation techniques are often used to find the best possible solution for a problem given a set of constraints and objectives. The objective can be to find the best value of a specific variable to either maximize or minimize the fit function. In the realm of ESSs, the size of the battery is a main contributor, particularly when the main objective is financial. If the battery size increases, it is able to store greater amounts of energy, which can then be economically rewarding.

However, due to the high per unit cost of the lithium-ion batteries, the larger the battery, the more costly the system gets. Therefore, finding the optimal or near optimal size of the battery where all costs are considered in the yearly cash flow and with respect to the operational lifespan of the battery requires the utilization of an optimisation technique. Techniques such as Linear Optimization and Genetic Algorithm are often used [51, 63, 64]

This research is employing PSO due to its flexibility, convergence to global optimum which provides high efficiency and robustness to uncertainty, as well as its ease of implementation. Each particle updates its position every iteration based on its personal best position, best globally among the particles, and its former speed vector as in (10). Equation (11) updates the particle's position, while (12) gradually decreases the inertia weight with each iteration to converge. The Pseudo code is shown in figure 2.

```
Initialize the controlling parameters ($N, c_1, c_2, w_{min}, w_{max}, V_{max}, and\ MaxIter$)
Initialize the population of N particles
do
        for each particle
                calculate the objective of the particle
                Update PBEST if required
                Update GBEST if required
        end for

        Update the inertia weight
        for each particle
                Update the Velocity (V)
                Update the Position (X)
        end for
while the end condition is not satisfied
Return GBEST as the best estimation of the global optimum
```

Figure 2: Pseudo code for PSO steps

$$v_i^{t+1} = w \times v_i^t + c_1 \times r_1 \times (PBEST - x_i^t) + c_2 \times r_2 \times (GBEST - x_i^t) \tag{10}$$

$$x_i^{t+1} = v_i^{t+1} + x_i^t \tag{11}$$

$$w = w_{max} - \frac{w_{max} - w_{min}}{MaxIter} \times iter \tag{12}$$

where N: The number of particles, v_i^{t+1}= The velocity of i^{th} particle at $(t+1)^{th}$ iteration, w: The inertia weight of the particle, v_i^t= The velocity of i^{th} particle at t^{th} iteration, c_1, c_2: The acceleration coefficients for exploitation and exploration, r_1, r_2= Randomly generated binary numbers, $PBEST$: The best position of the i^{th} particle obtained based upon its own experience gbest, $GBEST$: Global best position of the communicated particles in the population, x_i^t= The position of i^{th} particle at t^{th} iteration, w_{max} & w_{min}: Maximum and minimum values of inertia weight, *MaxIter*: Maximum number of iterations.

3.7 MODEL OBJECTIVE FUNCTION

The cost objective function for PSO utilized in this research, (13), is designed to maximize monetary benefits to the prosumers and taking into account all the factors. Based on the annual cash flow presented in (14), NPVs are then calculated in (15) for more accurate analysis by discounting futuristic cash flows, by an interest factor $\mathrm{I_r}$, to their present values.

$$\mathrm{Max(f)} = \mathrm{TCOE_{benefit}} - \frac{(\mathrm{Size_{CB}} * \mathrm{Cost}_{pu})}{B_{life}} \tag{13}$$

$$\begin{aligned} \mathrm{yearly_{cashflow}} = {} & \mathrm{TCOE_{benefit}} + Save_{emission}^{yr} - Cost_{Degradation}^{yr} \\ & - Cost_{Operation}^{yr} \end{aligned} \tag{14}$$

$$\mathrm{NPV} = \left(\sum_{\mathrm{i}=1}^{B_{life}} \left(\frac{\mathrm{yearly_{cashflow}}}{(1+\mathrm{I_r})^{\mathrm{i}}} \right) \right) - \mathrm{Cost}_{Battery} \tag{15}$$

3.8 MODEL CONSTRANTS & RESTRICTIONS

In To ensure both accuracy and authenticity of the proposed model and improve economic and operational performance, a number of constraints and regulations were considered, (16)-(20). These constraints serve a significant role to precisely reflect the real-world practical operational limitations and verify the optimization method's generated results are practical.

The battery's State of Charge (SOC) involves complex processes and techniques to precisely model. While the SOC determination is impacted by factors such as the operating conditions of the battery and battery ageing, which requires machine learning or traditional models to estimate [65], this study limits the SOC through industrial standards to avoid deep discharging and overcharging, conforming to battery management's recommended guidelines [66]. Equations (16) & (17) not only limits the SOC but also ensures continuity through subsequent days [67].

The battery's maximum charging capacity is set to restrict the charging of the community battery at time t to avoid overcharging beyond the specified manufacturer guidelines [68]. Moreover, the system exhibits a round-trip efficiency of a given percentage by the manufacturer [69]. This suggests that there is a percentage energy loss recorded throughout the energy transfers between individual houses and the community batteries, and vice versa, as referenced in the work of [15]. Equation (19) ensures the optimization returns a positive NPV, while (20) maintains balance in power at each step of the simulations.

$$SOC_{min} \leq SOC_{x,h} \leq SOC_{max} \quad \forall_{x,h} \tag{16}$$

$$SOC_{x+1,start} = SOC_{x,end} \quad \forall_{x} \tag{17}$$

$$\mathrm{P}_{\mathrm{bal-CB}}^{(\mathrm{h})} = \mathrm{Eff} * \sum_{\mathrm{h}=1}^{24} \mathrm{P}_{\mathrm{TCB}}^{(\mathrm{h})} \tag{18}$$

$$NPV > 0 \tag{19}$$

$$\begin{aligned} &\sum_{i=1}^{n} PV_i^{Gen}(x,h) \\ &\quad + \sum_{i=1}^{n} P_i^{B2H}(x,h) + \sum_{i=1}^{n} G_i^{s}(\mathrm{x},\mathrm{h}) \\ &\quad = \sum_{i=1}^{n} P_i^{Load}(x,h) + \sum_{i=1}^{n} P_i^{H2B}(x,h) \\ &\quad + \sum_{i=1}^{n} E_i^{surplus}(x,h) \end{aligned} \tag{20}$$

where $P_{TCB}^{(h)}$: the total power transactions, Eff: efficiency factor of the CBS, $P_{bal-CB}^{(h)}$: the total balanced power after the round-trip efficiency losses.

In the event of multiple load demands $P_i^{Load}(x,h)$ exceeding the available energy in the CB, the model prioritizes the house with highest cumulative contribution until time h of day x, encouraging more contributions and larger scaling of PVs. The proposed model is presented in (21) & (22).

$$E_i(x,h) = PV_i^{Gen}(x,h) - P_i^{Load}(x,h) \tag{21}$$

$$C_i(x,h) = \sum_{x'}^{x}\sum_{h'}^{h} E_i(x',h') \tag{22}$$

where $E_i(x,h)$: energy contribution by house i, $C_i(x,h)$: Cumulative contribution from start until day x and hour h, x' and h' iterate over preceding days until conflict.

3.9 SENSITIVITY & UNCERTAINTY ANALYSES

Sensitivity analysis assesses the influence level of selected components and help identify the most significant ones through deliberate manipulations of certain factors within practical ranges. The coefficient of variation (CV), a standardized measure of dispersion of a probability distribution, is used on the simulations' results to quantify the impact of each factor [70]. The larger the CV, the greater the vulnerability of the system to changes in the specific factor. Whereas a low value indicates high resistance of the model to the parameter's changes. It is calculated as the ratio of the standard deviation (σ) to the mean (μ) as shown in (23).

$$CV = \frac{\sigma}{\mu} \tag{23}$$

Due to the stochastic nature of solar, affecting PV power generation, and the subjection of loads to high volatility, uncertainty analysis utilizing Monte Carlo simulations based on probabilistic distribution entity is utilized [71]. The iterated simulations depict the potential weather conditions and potential grid consumption variations from the assumed model, by adding or subtracting generated variants defined by a standard deviation range. The method used is mathematically modelled in (24) & (25) respectively.

$$PV_{i*}^{Gen}(x,h) = PV_i^{Gen}(x,h) + V_i\,(x,h) \tag{24}$$

$$P_{i*}^{Load}(x,h) = P_i^{Load}(x,h) + V_i\,(x,h) \tag{25}$$

where PV_{i*}^{Gen}& P_{i*}^{Load}: The adjusted PV generation and Load, equivalent to the sum of base values and the random variation V_i, and $V_i \sim N(\mu,\sigma)$, for iteration i. V_i is drawn from a normal distribution with mean $\mu = 0$, and standard deviation σ.

Chapter 4: Results & Discussion

4.1 INPUT PARAMETERS

The number of households chosen for this study is five, to limit computational time, considering each has different load demand. All share the same PV generation as varying this parameter is not within the scope of this research, and they are considered to be in same locality. The per-hour household consumption data and solar generation data are both taken from [56]. The daily average load demand and PV generation curves of each household are shown in Figure 3. Table 2 summarizes the settings specified for the simulation. A thorough re-view of existing literature and industry standards determined the selection of parameters to accurately evaluate the effectiveness of the model [10, 31, 69, 72-76]. PSO and simulations in this research were conducted on three different cases using MATLAB, summarized as:

- Case 1: Prosumers-owned CBS to serve the community, optimized based on the mathematical model.
- Case 2: Multiple home-owned batteries for comparison with community battery outcomes in the first case.
- Case 3: A novel scheme where the CBS capacity is optimized to not only serve the community but also feed larger consumers like business and industrial areas.

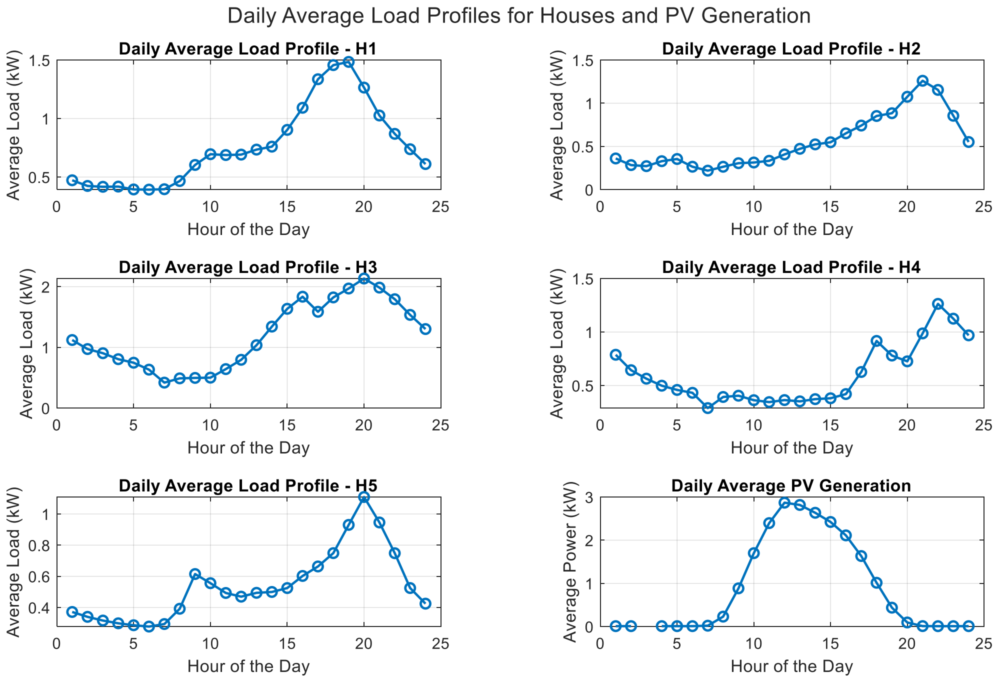

Figure 3: Daily average load profiles and PV Generation

Table 2: Input Parameters

Parameter	Value	Parameter	Value
$\mathrm{Cost_k}\ 15 \le \mathrm{h} \le 22$	0.43 AUD	$\beta_\zeta \rightarrow \beta_{FiT}$	0.1 AUD
$\mathrm{Cost_k}\ 1 \le \mathrm{h} < 9$	0.28 AUD	$\beta_\zeta \rightarrow \beta_{LL}$	0.35 AUD
$\mathrm{Cost_k}\ 9 \le \mathrm{h} < 15 \mid 22 < \mathrm{h} \le 24$	0.35 AUD	$Cost_{pu}$	500 AUD
λ^{sell}	0.10 AUD	SOC_{min}	0.1
λ^{buy}	0.16 AUD	SOC_{max}	0.95
ACC	500 AUD	$\mathrm{I_r}$	0.08
$\mathrm{Cost_{IC}}$	1000 AUD	Eff	95%
$Cost_{LUoS}$	0.02 AUD	ADR	0.015
n	5 houses	ASL	0.075
acceleration coefficients (c1, c2)	1.5	B_{life}	10 years
Number of populations for PSO	20	Inertia weight (w)	0.5
E_c	56.42	$iter$	20
E_{pu}	0.51	Number of Scenarios for PSO	100

4.2 CASE STUDIES

PSO simulations' results from (10) & (12) offer comparisons among various battery utilisation scenarios in a community setting which can lead to valuable insights. The results for each case are presented in Table 3. Equations (1)-(3) are adjusted for case 2 to calculate individual rather than collective outcomes. In case 3, (4) utilizes a higher β_ζ rate than the FiT rate by using an average value of the ToU prices. This indicates that the surplus green energy can benefit both the community, financially, as well as the large load with a non-costly transition to clean energy.

NPVs for individual households when each owns their own respective home batteries varies between 4164.10AUD and 5624.82 AUD, amounting to 25,525.73 AUD in total for a clustered battery size of 32 kWh for case 2. This combined total is lower than the returned NPV in case 1, 35,141.36AUD, where a community battery is shared and owned by the prosumers. The optimal battery size for the community battery is 24kwh, indicating that battery utilization is improved when it aggregates the supply and demand profiles of several houses. This occurs as the combining of loads can smoothen the peaks and valleys of demand.

In addition, with multiple houses the distinct consumption patterns balance out, leading to a consistent and more efficient battery utilization in higher rates and lower underutilization. This is known in the distribution system field as “diversified demand” [77]. This can be seen in Figure 4. Therefore, while individual home batteries may offer customized solutions, they may not be as economically advantageous as community batteries.

Table 3: Comparison of Results

Case Studies	NPV ($)	Battery Size (kWh)
Case Study 1	35,141.36	24
Case Study 2	25,525.73	32
Case Study 3	56,174.30	30

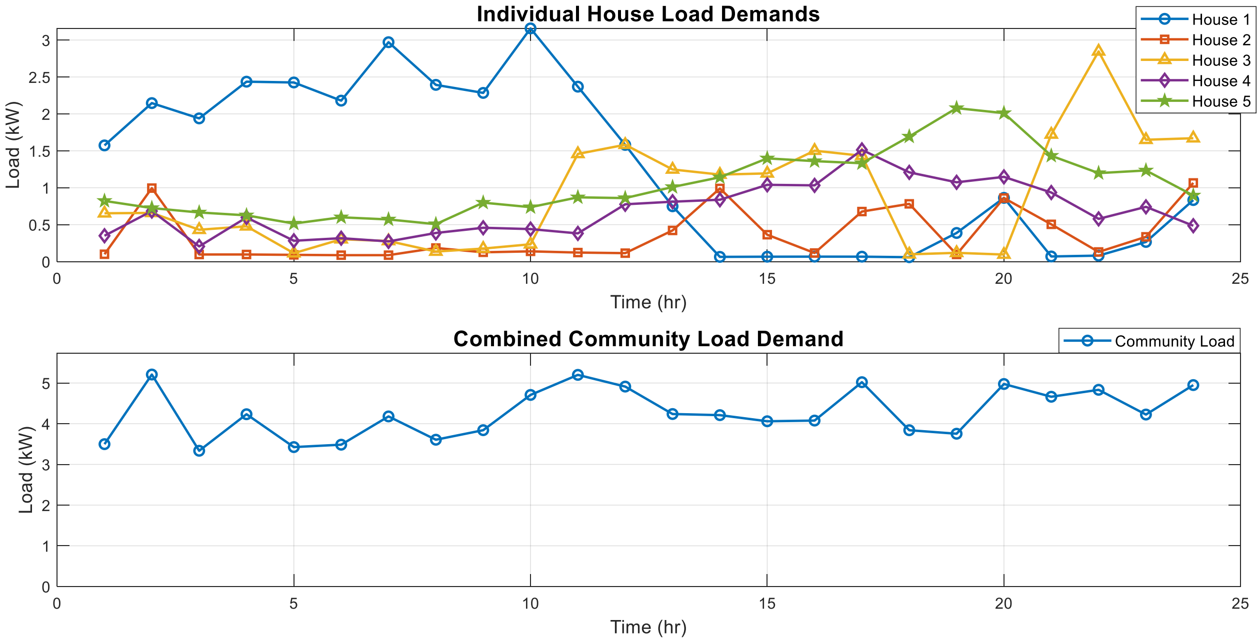

Figure 4: Individual vs clustered load demand data samples

Lastly, the introduction of additional potential scheme, larger consumers, returned an optimal battery size of 30kwh, yielding to the highest NPV value out of all three case studies of 56,174.30AUD. In comparison with case 2, for a smaller size with respect to the combined sizes of home batteries, the NPV is more than doubled. This exemplifies the capacity of the community battery to not only cater to the energy requirements of a certain locality but also to supply larger consumers

4.3 SENSITIVITY & UNCERTAINTY ANALYSES

Sensitivity analysis was conducted on three parameters: the cost per unit of the battery, ADR, and the interest rate affecting the NPV. Some research indicates that there could be a decrease in lithium-ion battery costs [78], others point to uncertainties and possible increases due to fluctuations in raw material prices [79]. Therefore, the per unit cost of the battery was adjusted systematically from -30% to +30% in increments of 5% relative to its base value of 0%. This was applied on other parameters for direct comparison using coefficient of variation. The selected ranges encompass potential variations influenced by technological advancements and market dynamics [10, 69].

Summary of the sensitivity analysis results is tabulated in Table 4 below to provide an overview of the impacts each parameter implied on the NPV and battery size over the three distinct scenarios. Figure 5 presents the slopes of deviations from base values across the 3 parameters. The steeper the slope the more sensitive the results are to the parameter.

Table 4: Summary of Sensitivity Analysis Results

Means of measurements	Per Unit Cost	ADR	Interest Rate (IR)
Coefficient of Variation	0.034	2.5×10^{-7}	0.093
Impact Level on NPV	Moderate	Negligible	High

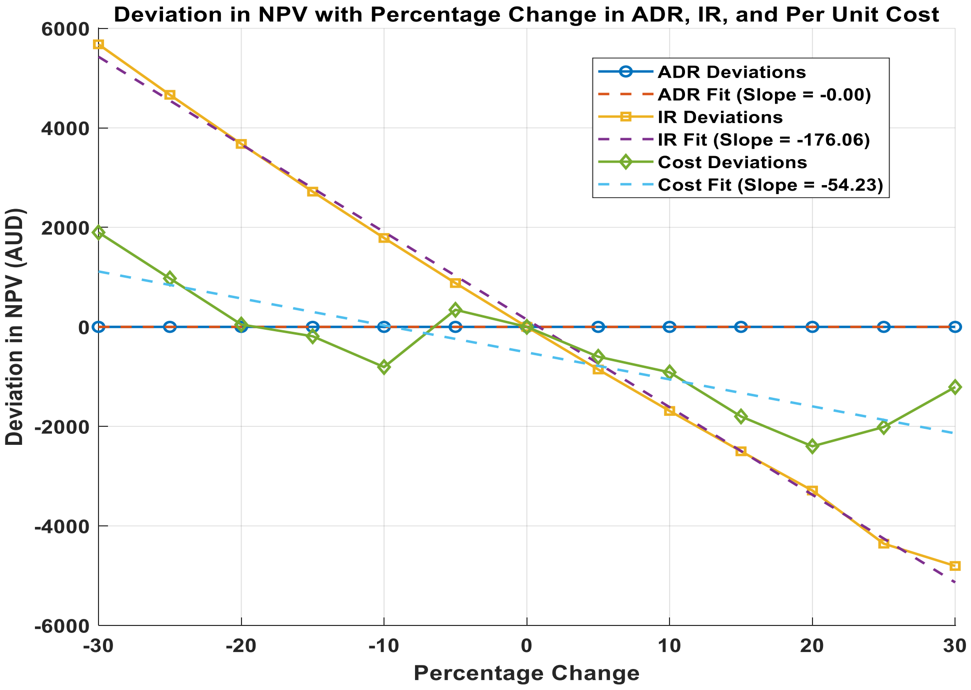

Figure 5: Deviation in NPV with percentage change in parameters

To reflect the stochastic variability of solar power and volatility of load demands, Monte Carlo simulations were used to generate 100 random scenarios for PV output and individual loads over the 10 years period based on normal distribution with a standard deviation of ±10% variation for solar and ±15% for the loads with a mean of zero. This was performed on the main case integrating the proposed CBS's model, case 1. The histogram in Figure 6 displays the mean simulated PV generation (kWh) which calculates average PV generation over a given period based on the integrated daily PV power (kW), while Figure 7 shows the histograms for the mean simulated data of the 5 households. Figure 8 and Figure 9 present the range and frequency of NPVs as well as overlayed PDF curves to present the likelihood of each result for PV and load variations, respectively, highlighting the potential risks and benefits.

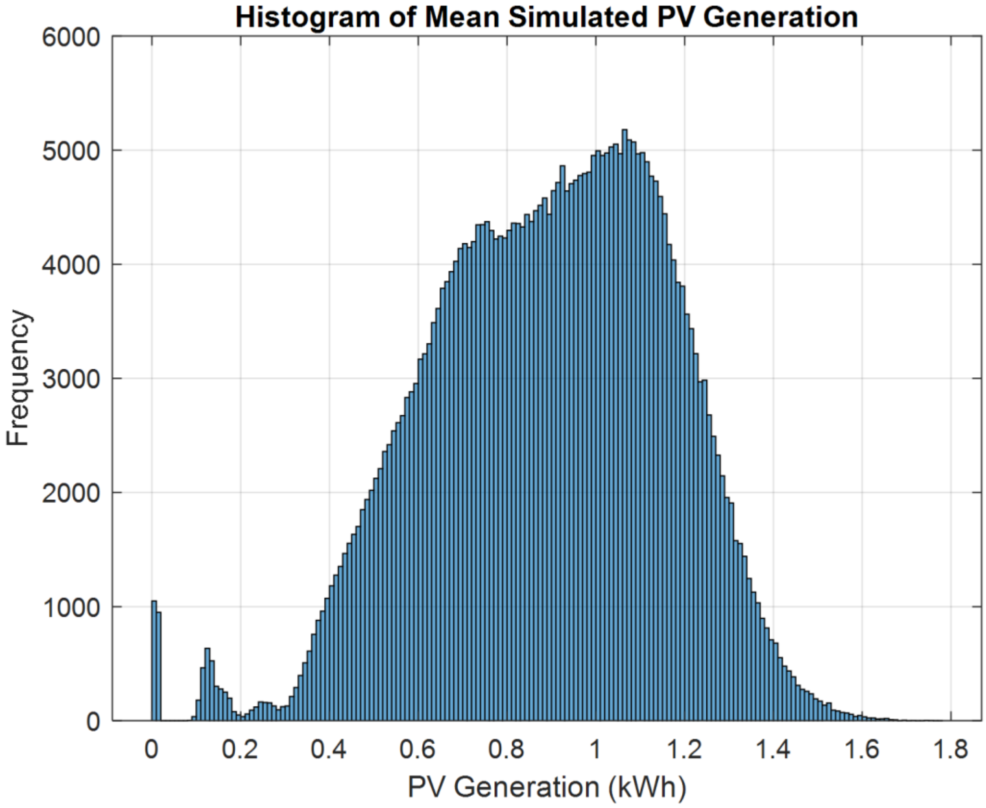

Figure 6: Histogram of Mean Simulated PV Generations

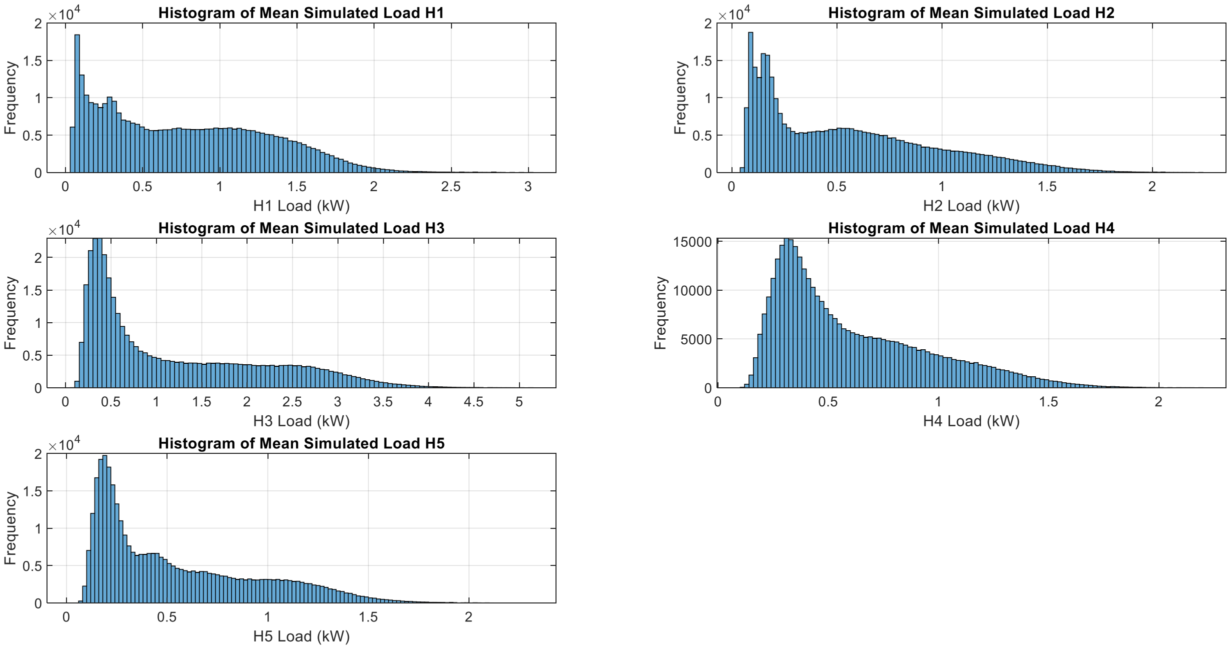

Figure 7: Histogram of Mean Simulated Load Demands

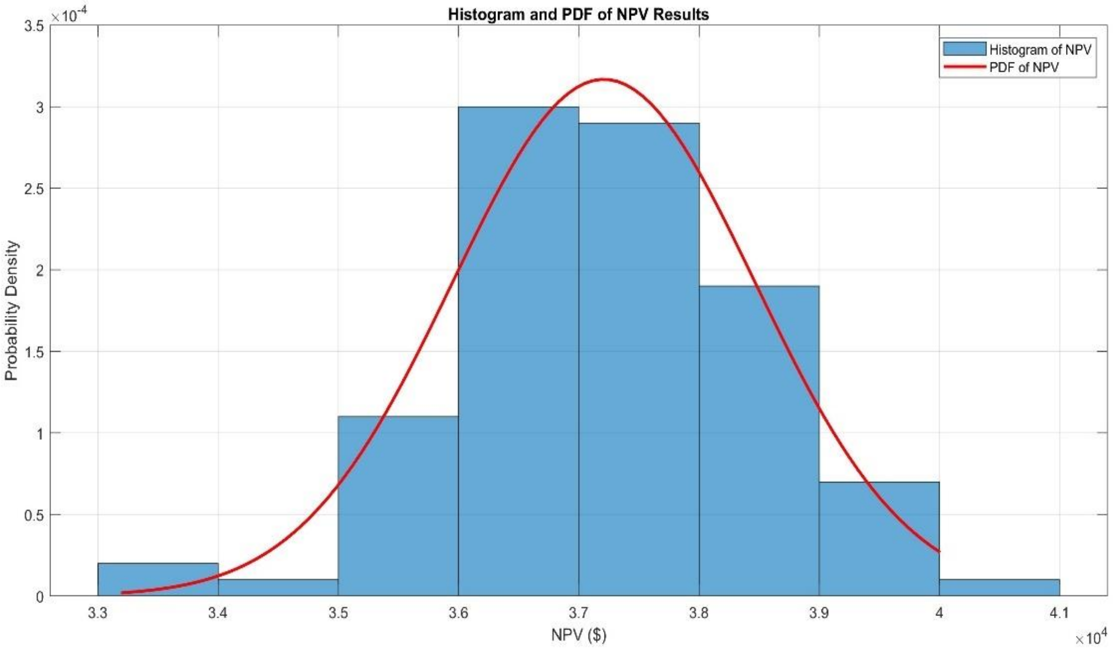

Figure 8: Histogram & PDF of NPV results for PV variations

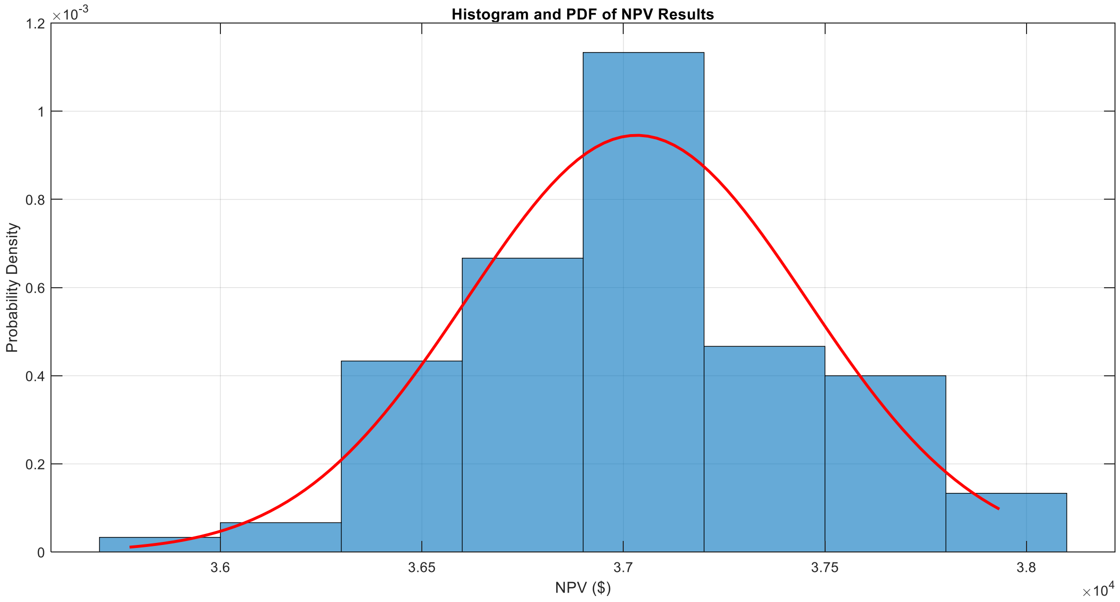

Figure 9: Histogram & PDF of NPV results for Load variations

To further assess the risks associated with PV and load variations, cumulative density functions (CDF) of the NPVs outcomes are presented in Figure 10 and Figure 11. The CDF represents the probability of the NPV to be less than or equal to the given values. Both figures display positive returns demonstrating the robustness of the proposed system.

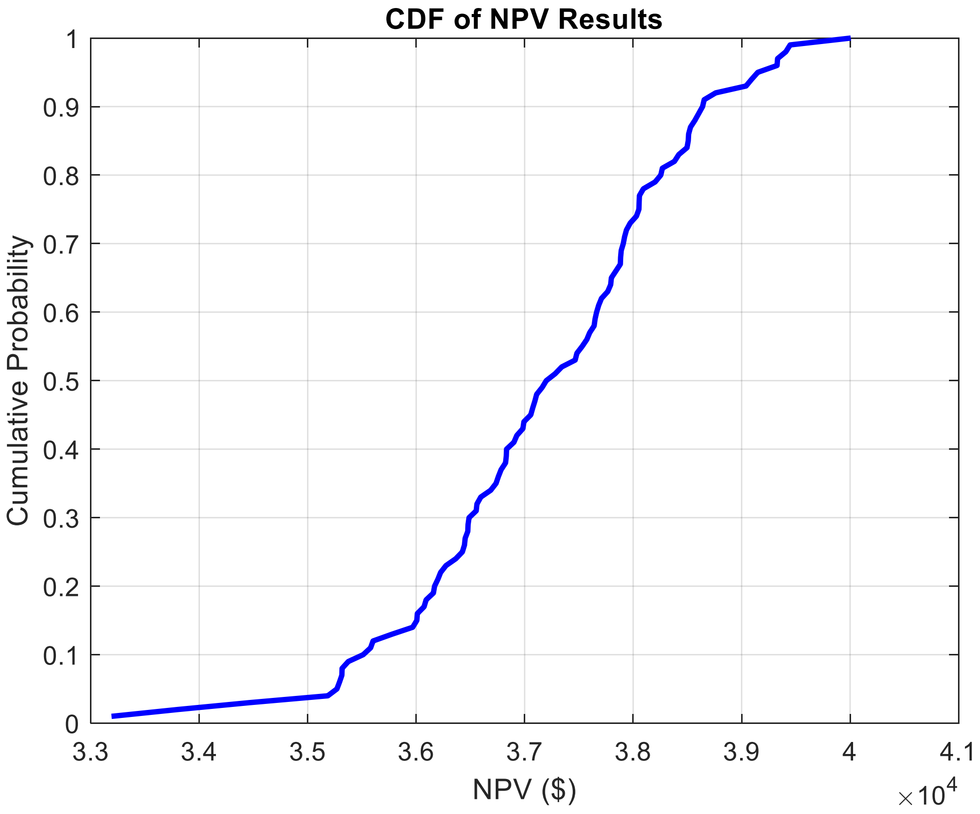

Figure 10: Cumulative Probability of NPV under varying PV generations

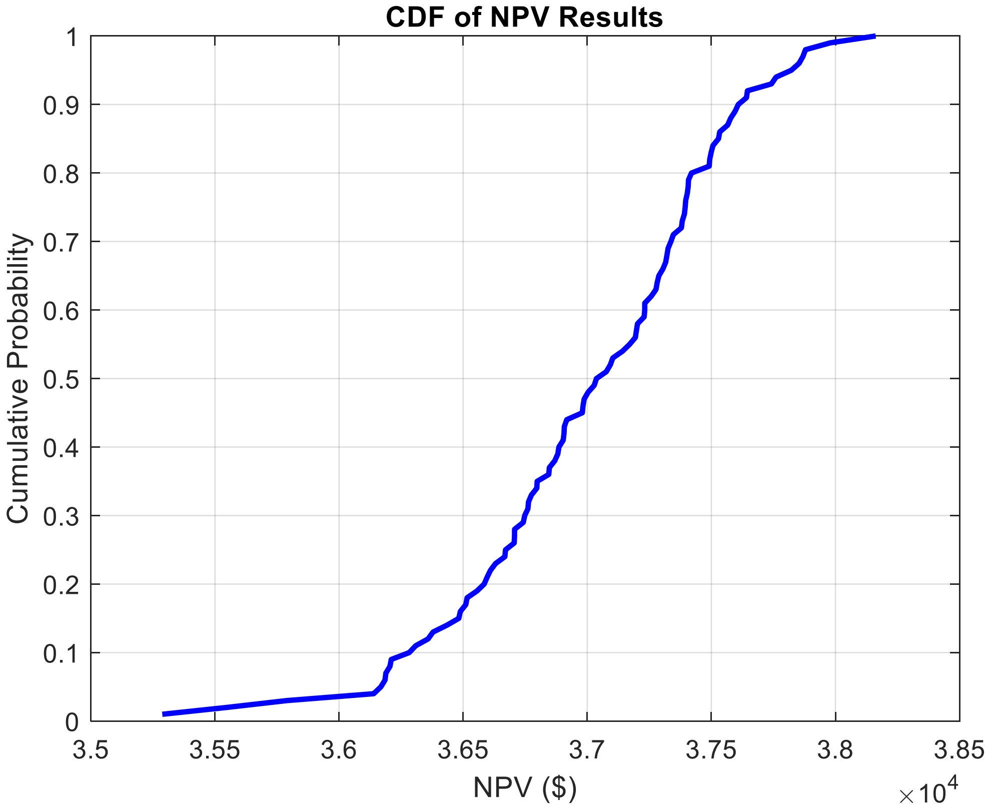

Figure 11: Cumulative Probability of NPV under varying load demands

Based on the results and the calculated CV values which provide a standardized measure of variability, for each parameter, the interest rate was outlined to have the greatest impact on the NPV. Following that was the per unit cost of the battery with also relatively high impact, and lastly the annual degradation rate with minimal impact on the outcomes. This indicates that the interest rate and battery cost play significant roles in determining the economic viability of community battery systems.

Uncertainty simulations produced a mean NPV of 37207.58AUD for Monte Carlo simulated PV generations and a mean NPV of 37015.55AUD for Monte Carlo simulated load demands. Deviating by 1259.59AUD and 1874.19AUD, the uncertainty results indicate positive returns with moderate variability due to the inherent randomness in solar and volatility of load demands. The PDF and histograms further highlight risks and profitability by showing PV generation and load demands possibilities with their resulting NPVs. The use of Monte Carlo simulations has increased confidence in forecasting models, under circumstances, and provides reliability in practice.

4.4 IMPACT OF TARIFF STRUCTURES ON NPV & BATTERY SIZING

To evaluate the performance of the system under different pricing schemes, simulations were conducted under various common tariff structures. Not only will the results provide an outlook of different tariff structures impacts on the proposed model, but also determine the most advantageous ones for community battery integration. The explored tariff structures are Block Tariff, Seasonal Tariff, TOU, Flat rate Tariff, and CPP. A summary of each of the tariff's pricing schemes is tabulated in Table 6. Results of the simulations are presented in Table 5 and Figure 12.

Table 5: Tariff structures: Analysis' results

Tariff Structure	Case Study 1		Case Study 2		Case Study 3	
	Battery Size (kWh)	NPV (AUD)	Battery Size (kWh)	NPV (AUD)	Battery Size (kWh)	NPV (AUD)
Block Tariff	38	26622.62	35	16529.08	35	54270.13
Seasonal Tariff	31	18058.91	16	19340.98	31	44978.40
TOU	24	35141.36	27	26971.34	31	63588.50
Flat Tariff	40	29098.74	40	16823.03	37	61710.63
CPP	39	45542.04	35	27065.95	33	70252.03

Table 6: Tariff Structures & Pricing Schemes

Tariff Structure	Pricing Scheme
Block Tariff	Block 1: $0.3536 per kWh (first 30 units/day) Block 2: $0.3937 per kWh (31-1650 units/day) Block 3: $0.3755 per kWh (over 1650 units/day)
Seasonal Tariff	Normal: $0.22 per kWh (non-critical times) Summer: $0.33 per kWh (June-September) Winter: $0.15 per kWh (October-May)
TOU	Peak: $0.4323 per kWh (3pm-10pm) Off-peak: $0.35332 per kWh (12am-9am) Shoulder: $0.28578 per kWh (9am-3pm, 10pm-12am)
Flat Tariff	$0.40 per kWh
CPP	Critical Peak: $0.50 per kWh (daily 18, 19, 20, 21 hours) Normal: $0.15 per kWh

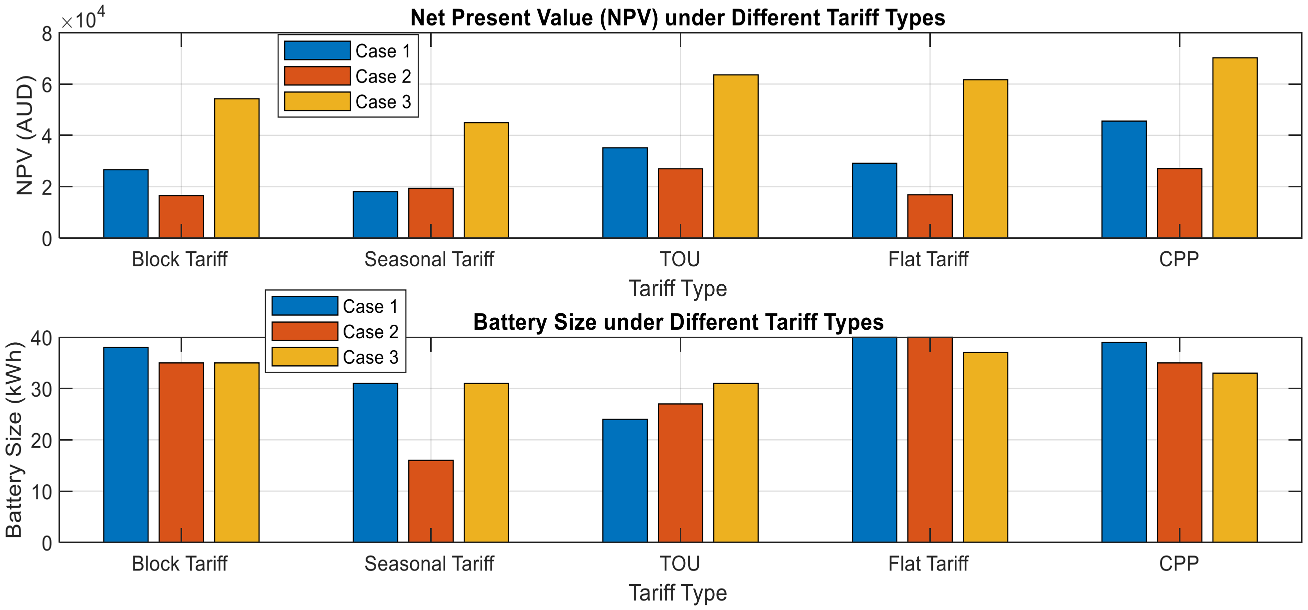

Figure 12: Impact of Different Tariff Structures on NPV and Battery Size

Consistently yielding the greatest NPV in all cases, CPP and TOU tariffs allow for strategic utilization of the battery during periods of high costs, thereby maximizing financial returns. In Case 3 in which the community battery serves both the community and larger consumers, CPP returned the highest NPV of 70252.03 AUD. This indicates effective employment of the battery in such scenarios. Moderately favourable structures were both the

Flat and Block tariffs. While the Flat tariff returned a more consistent and predictable revenue, the Block tariff's hierarchical structure produced varying results depending on levels of consumption. In cases 1 and 2, Flat tariff's simulations suggested the largest size out of all, which indicates a preference in greater storage to make the most out of the fixed pricing.

Despite the high summer rates, Seasonal tariff returned the lowest NPVs. This is due to the low winter rates which reduce the overall potential earnings over the year. In case 2, the battery size required under Seasonal tariff was significantly lower, reflecting a reduction in the optimization potential. Between the main cases, case 1 and case 3, the implementation of the CPP and Block tariff structures led to larger battery sizes, reflecting a strategy of optimizing the storage's capacity in peak price periods.

Lastly, the battery sizes results displayed greater uniformity and consistency in case 3 across various schemes. This suggests that although there are major discrepancies between various systems, the additional capacity required to cater to the larger consumers mitigate those disparities.

The findings highlight the economic advantage that CBs offer over individual home batteries. Moreover, the incorporation of larger consumers seeking carbon footprint reduction returned a further enhanced NPV, outlining different potential revenue streams in such projects. The analysis of various tariff structures has also determined CPP to be the most profitable, due to the strategic utilization of battery during higher rate periods.

Chapter 5: Conclusion & Future Work

This thesis aimed to develop a holistic approach, by which it can assist to optimize the economic performance of community battery systems in conjunction with PV generation and maximize the returns to the prosumers owning the shared battery. The proposed paradigm takes into account several key factors, a few of which can often be neglected such as network costs, degradation costs, and quantified monetary benefits from carbon emission reduction. PSO was used to optimize the battery size for maximum NPV returns in various scenarios and pricing models. Community batteries proved to be more financially viable than home batteries, especially under CPP scheme.

This was due to these models enabling strategic utilisation of the battery during periods of higher costs. A novel scheme of considering and integrating major energy users, wanting to lower their carbon footprint, highlighted community battery's potential to both support broader energy networks and promote environmental practices. Lastly, the sensitivity analysis results demonstrated significant influence on the NPV by the interest rate, followed by the unit cost of the battery. While the annual degradation rate had a minor effect on the final outcomes. An uncertain analysis conducted on the PV generation highlighted the imperativeness of taking into account random characteristics associated with renewable energy when sizing community batteries. This was underscored through the significant variances in the Monte Carlo simulations' outcomes.

While this study presents an extensive methodology and through analysis, future works can further build upon and broaden this work's findings through a number of avenues. Shared community batteries require prosumers interactions and engagements. It is important to analyze the social and behavioral factors in order to deploy such systems effectively. Future research can also explore the integration of CBSs with other energy storage technologies and their role in grid stabilization. Evaluating and assessing various battery technologies through comparative assessments may also provide a more profound understanding and selecting the most suitable for specific communities. This includes solid-state batteries, flow batteries, vanadium redox, and hybrid systems.

Ethical and Safety Issues

This research primarily involves simulations, data analysis, and optimisation algorithms in the context of energy systems with no direct engagement of human participants or the exploitation of sensitive personal data. Therefore, it may be concluded that there are no ethical considerations associated with human involvement or the protection of data privacy. Furthermore, the study does not entail any form of empirical investigation or the use of substances that pose possible dangers, hence mitigating potential safety hazards. Based on the provided background, it can be concluded that this study does not need any particular ethical or safety considerations.

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Appendix A: MATLAB Code for Case 1

```
clc
clear all close all

% Yearly LOAD DEMAND of EACH HOUSE
H1=xlsread('DATA.xlsx','H1');
H2=xlsread('DATA.xlsx','H2');
H3=xlsread('DATA.xlsx','H3');
H4=xlsread('DATA.xlsx','H4');
H5=xlsread('DATA.xlsx','H5');

[hours, days] = meshgrid(1:24, 1:365);

%yearly Pv generation
PV=xlsread('DATA.xlsx','PV');


%Parameters Initiation
% initial investment cost B=data_final;
CB=500;% CB=per unit battery cost CI=1000;%
CI= Cost of Installation grid_sell_price=0.07;
%Feed in Tariff
%battery degradation costs
ADR=0.015;
CE=0.15; BL=10;
%battery operation cost CE=0.15;
ACC=500;
CPC=0.2;
%intrest rate
I_r=0.08;
period=10; %Battery Life
%PARAMETER SET (TARIFF PRICE 24 hour)
%tariff prices in AUD peak_price=0.43;%3pm-
10pm offpeak_price=0.28;%12am-9am
shoulder_price=0.35;%9am-3pm,10pm-12pm

%PSO Parameters
max_soc=0.95; % max soc
min_soc=0.10;%min soc
no_of_par=10;% number of particles
no_of_iteration=20;% no of iterations

for h=1:24
    if h>14 && h<21 tariff(h)=peak_price;
    elseif (h>7 && h<14) || (h==21)|| (h==22) tariff(h)=shoulder_price;
```

```
    else
        tariff(h)=offpeak_price;

    end


    tariff(25)=offpeak_price;
end

% pv+charging loop
cbp1=zeros(365,24);   %   charging   battery   power
cbp2=zeros(365,24);
cbp3=zeros(365,24);
cbp4=zeros(365,24);
cbp5=zeros(365,24);

for i=1:365
    %  House 1 for
    ii=1:24
        if(PV(i,ii)>0.02 && PV(i,ii)<H1(i,ii));
            gsp1(i,ii)=H1(i,ii)-PV(i,ii);
            pvsp1(i,ii)=PV(i,ii); ptb1(i,ii)=0;
            bsp1(i,ii)=0;

        elseif(PV(i,ii)>H1(i,ii));
            gsp1(i,ii)=0; %grid supply power (gsp) pvsp1(i,ii)=H1(i,ii); % PV
            supply power (pvsp) ptb1(i,ii)=PV(i,ii)-H1(i,ii); % power to battery (ptb)
            cbp1(i,ii)=ptb1(i,ii)+cbp1(i,ii-1);
            bsp1(i,ii)=0; %battery supply power else(PV(i,ii)==0 ||
        PV(i,ii)<0.02);
            gsp1(i,ii)=H1(i,ii); pvsp1(i,ii)=0;
            ptb1(i,ii)=0;
            bsp1(i,ii)=0;


        end
    end
    CBsize_h1(i)=sum(ptb1(i,:));
    %house 2 for
    ii=1:24
        if(PV(i,ii)>0.02 && PV(i,ii)<H2(i,ii));
            gsp2(i,ii)=H2(i,ii)-PV(i,ii);
            pvsp2(i,ii)=PV(i,ii); ptb2(i,ii)=0;
            bsp2(i,ii)=0;

        elseif(PV(i,ii)>H2(i,ii));
            gsp2(i,ii)=0; %grid supply power (gsp) pvsp2(i,ii)=H2(i,ii); % PV
            supply power (pvsp) ptb2(i,ii)=PV(i,ii)-H2(i,ii); % power to battery (ptb)
            cbp2(i,ii)=ptb2(i,ii)+cbp2(i,ii-1);
            bsp2(i,ii)=0; %battery supply power else(PV(i,ii)==0 ||
        PV(i,ii)<0.02);
```

```
        gsp2(i,ii)=H2(i,ii); pvsp2(i,ii)=0;
        ptb2(i,ii)=0;
        bsp2(i,ii)=0;

    end
end
CBsize_h2(i)=sum(ptb2(i,:));
%house 3 for
ii=1:24
    if(PV(i,ii)>0.02 && PV(i,ii)<H3(i,ii));
        gsp3(i,ii)=H3(i,ii)-PV(i,ii);
        pvsp3(i,ii)=PV(i,ii); ptb3(i,ii)=0;
        bsp3(i,ii)=0;

    elseif(PV(i,ii)>H3(i,ii));
        gsp3(i,ii)=0; %grid supply power (gsp) pvsp3(i,ii)=H3(i,ii); % PV
        supply power (pvsp) ptb3(i,ii)=PV(i,ii)-H3(i,ii); % power to battery (ptb)
        cbp3(i,ii)=ptb3(i,ii)+cbp3(i,ii-1);
        bsp3(i,ii)=0; %battery supply power else(PV(i,ii)==0 ||
    PV(i,ii)<0.02);
        gsp3(i,ii)=H3(i,ii); pvsp3(i,ii)=0;
        ptb3(i,ii)=0;
        bsp3(i,ii)=0;

    end
end
CBsize_h3(i)=sum(ptb3(i,:));
%house 4 for
ii=1:24
    if(PV(i,ii)>0.02 && PV(i,ii)<H4(i,ii));
        gsp4(i,ii)=H4(i,ii)-PV(i,ii);
        pvsp4(i,ii)=PV(i,ii); ptb4(i,ii)=0;
        bsp4(i,ii)=0;

    elseif(PV(i,ii)>H4(i,ii));
        gsp4(i,ii)=0; %grid supply power (gsp) pvsp4(i,ii)=H4(i,ii); % PV
        supply power (pvsp) ptb4(i,ii)=PV(i,ii)-H4(i,ii); % power to battery (ptb)
        cbp4(i,ii)=ptb4(i,ii)+cbp4(i,ii-1);
        bsp4(i,ii)=0; %battery supply power else(PV(i,ii)==0 ||
    PV(i,ii)<0.02);
        gsp4(i,ii)=H4(i,ii); pvsp4(i,ii)=0;
        ptb4(i,ii)=0;
        bsp4(i,ii)=0;

    end
end
CBsize_h4(i)=sum(ptb4(i,:));
```

```
    %house 5 for
    ii=1:24
        if(PV(i,ii)>0.02 && PV(i,ii)<H5(i,ii));
            gsp5(i,ii)=H5(i,ii)-PV(i,ii);
            pvsp5(i,ii)=PV(i,ii); ptb5(i,ii)=0;
            bsp5(i,ii)=0;

        elseif(PV(i,ii)>H5(i,ii));
            gsp5(i,ii)=0; %grid supply power (gsp) pvsp5(i,ii)=H5(i,ii); % PV
            supply power (pvsp) ptb5(i,ii)=PV(i,ii)-H5(i,ii); % power to battery (ptb)
            cbp5(i,ii)=ptb5(i,ii)+cbp5(i,ii-1);
            bsp5(i,ii)=0; %battery supply power else(PV(i,ii)==0 ||
        PV(i,ii)<0.02);
            gsp5(i,ii)=H5(i,ii); pvsp5(i,ii)=0;
            ptb5(i,ii)=0;
            bsp5(i,ii)=0;

        end
    end
    CBsize_h5(i)=sum(ptb5(i,:));
    PDB_size(i)=sum(CBsize_h1(i)+CBsize_h2(i)+CBsize_h3(i)+CBsize_h4(i)+CBsize_h5↙ (i));
end

%INTIAL PRICE CALCULATION FOR THE YEAR
for i=1:365
    for ii=1:24
        h_h1(i,ii)=(H1(i,ii)-pvsp1(i,ii))*tariff(1,ii);
        h_h2(i,ii)=(H2(i,ii)-pvsp2(i,ii))*tariff(1,ii);
        h_h3(i,ii)=(H3(i,ii)-pvsp3(i,ii))*tariff(1,ii);
        h_h4(i,ii)=(H4(i,ii)-pvsp4(i,ii))*tariff(1,ii);
        h_h5(i,ii)=(H5(i,ii)-pvsp5(i,ii))*tariff(1,ii);
    end d_h1(i)=sum(h_h1(i,:));
    d_h2(i)=sum(h_h2(i,:));
    d_h3(i)=sum(h_h3(i,:));
    d_h4(i)=sum(h_h4(i,:));
    d_h5(i)=sum(h_h5(i,:)); t_d(i)=sum(h_h1(i,:)+h_h2(i,:)+h_h3(i,:)+h_h4(i,:)+h_h5(i,:));



end

i=1:365;


%   Discharging   Loop
x1=gsp1;
x2=gsp2;
x3=gsp3;
x4=gsp4;
x5=gsp5;
z1=bsp1;
z2=bsp2;
```

```
z3=bsp3;
z4=bsp4;
z5=bsp5;


%discharging loop
Round_trip_effecincy=0.95;
CBSP=0.10;% community battery selling power price CBBP=0.16;%
Community battery Buying power price

for i=1:365
    size=PDB_size(1,i); gsp1=x1;
    gsp2=x2;
    gsp3=x3;
    gsp4=x4;
    gsp5=x5;
    bsp1=z1;
    bsp2=z2;
    bsp3=z3;
    bsp4=z4;
    bsp5=z5;
    bdp1=zeros(365,24);
    bdp2=zeros(365,24);
    bdp3=zeros(365,24);
    bdp4=zeros(365,24);
    bdp5=zeros(365,24);

    for ii=1:365
        size=PDB_size(1,i);
        if size>PDB_size(1,ii)
            size=PDB_size(1,ii);
        elseif size<PDB_size(1,ii) size=size;
        else
            size=PDB_size(1,ii);
        end

        size=size*Round_trip_effecincy; for iii=1:24
            if(gsp1(ii,iii)>0 && tariff(iii)==peak_price && size>0);
                bsp1(ii,iii)=min(size,gsp1(ii,iii)); bdp1(ii,iii)=size-gsp1(ii,iii);
                size= bdp1(ii,iii); gsp1(ii,iii)=gsp1(ii,iii)-bsp1(ii,iii);
            end

            if(gsp2(ii,iii)>0 && tariff(iii)==peak_price && size>0);
                bsp2(ii,iii)=min(size,gsp2(ii,iii)); bdp2(ii,iii)=size-gsp2(ii,iii);
                size= bdp2(ii,iii); gsp2(ii,iii)=gsp2(ii,iii)-bsp2(ii,iii);
            end

            if(gsp3(ii,iii)>0 && tariff(iii)==peak_price && size>0);
```

```
          bsp3(ii,iii)=min(size,gsp3(ii,iii)); bdp3(ii,iii)=size-
          gsp3(ii,iii); size= bdp3(ii,iii);
          gsp3(ii,iii)=gsp3(ii,iii)-bsp3(ii,iii);


      end


      if(gsp4(ii,iii)>0 && tariff(iii)==peak_price && size>0);
          bsp4(ii,iii)=min(size,gsp4(ii,iii)); bdp4(ii,iii)=size-gsp4(ii,iii);
          size= bdp4(ii,iii); gsp4(ii,iii)=gsp4(ii,iii)-bsp4(ii,iii);
      end

      if(gsp5(ii,iii)>0 && tariff(iii)==peak_price && size>0);
          bsp5(ii,iii)=min(size,gsp5(ii,iii)); bdp5(ii,iii)=size-gsp5(ii,iii);
          size= bdp5(ii,iii); gsp5(ii,iii)=gsp5(ii,iii)-bsp5(ii,iii);
      end
  end
  for iii=1:24
      if(gsp1(ii,iii)>0 && tariff(iii)==shoulder_price && size>0); bsp1(ii,iii)=min(size,gsp1(ii,iii));
          bdp1(ii,iii)=size-gsp1(ii,iii); size=bdp1(ii,iii);
          gsp1(ii,iii)=gsp1(ii,iii)-bsp1(ii,iii);
      end

      if(gsp2(ii,iii)>0 && tariff(iii)==shoulder_price && size>0); bsp2(ii,iii)=min(size,gsp2(ii,iii));
          bdp2(ii,iii)=size-gsp2(ii,iii); size=bdp2(ii,iii);
          gsp2(ii,iii)=gsp2(ii,iii)-bsp2(ii,iii);
      end

      if(gsp3(ii,iii)>0 && tariff(iii)==shoulder_price && size>0); bsp3(ii,iii)=min(size,gsp3(ii,iii));
          bdp3(ii,iii)=size-gsp3(ii,iii); size=bdp3(ii,iii);
          gsp3(ii,iii)=gsp3(ii,iii)-bsp3(ii,iii);
      end

      if(gsp4(ii,iii)>0 && tariff(iii)==shoulder_price && size>0); bsp4(ii,iii)=min(size,gsp4(ii,iii));
          bdp4(ii,iii)=size-gsp4(ii,iii); size=bdp4(ii,iii);
          gsp4(ii,iii)=gsp4(ii,iii)-bsp4(ii,iii);
      end

      if(gsp5(ii,iii)>0 && tariff(iii)==shoulder_price && size>0); bsp5(ii,iii)=min(size,gsp5(ii,iii));
          bdp5(ii,iii)=size-gsp5(ii,iii); size=bdp5(ii,iii);
          gsp5(ii,iii)=gsp5(ii,iii)-bsp5(ii,iii);
```

```
            end
        end
    end

     for ii=1:365 for
        iii=1:24

            AC_H1(ii,iii)=gsp1(ii,iii)*tariff(iii); AC_H2(ii,iii)=gsp2(ii,iii)*tariff(iii);
            AC_H3(ii,iii)=gsp3(ii,iii)*tariff(iii); AC_H4(ii,iii)=gsp4(ii,iii)*tariff(iii);
            AC_H5(ii,iii)=gsp5(ii,iii)*tariff(iii); sp_H1(ii,iii)=CBSP*ptb1(ii,iii);
            sp_H2(ii,iii)=CBSP*ptb2(ii,iii); sp_H3(ii,iii)=CBSP*ptb3(ii,iii);
            sp_H4(ii,iii)=CBSP*ptb4(ii,iii); sp_H5(ii,iii)=CBSP*ptb5(ii,iii);
            BCB_H1(ii,iii)=CBBP*bsp1(ii,iii); BCB_H2(ii,iii)=CBBP*bsp2(ii,iii);
            BCB_H3(ii,iii)=CBBP*bsp3(ii,iii); BCB_H4(ii,iii)=CBBP*bsp4(ii,iii);
            BCB_H5(ii,iii)=CBBP*bsp5(ii,iii);
        end
        TAC_H1(i,ii)=sum(AC_H1(ii,:));
        TAC_H2(i,ii)=sum(AC_H2(ii,:));
        TAC_H3(i,ii)=sum(AC_H3(ii,:));
        TAC_H4(i,ii)=sum(AC_H4(ii,:));
        TAC_H5(i,ii)=sum(AC_H5(ii,:));

     end
     for ii=1:365
         TAC_H(i,ii)=sum( AC_H1(ii,:)+AC_H2(ii,:)+AC_H3(ii,:)+AC_H4(ii,:)+AC_H5↙
(ii,:));
         Tsp_H(i,ii)=sum(sp_H1(ii,:)+sp_H1(ii,:)+sp_H3(ii,:)+sp_H4(ii,:)+sp_H5↙
(ii,:));
         TBCB_H(i,ii)=sum( BCB_H1(ii,:)+BCB_H2(ii,:)+BCB_H3(ii,:)+BCB_H4(ii,:)↙
+BCB_H5(ii,:));
     end
    CEB(i)=sum(TAC_H(i,:))+sum(Tsp_H(i,:))-sum(TBCB_H(i,:));
end

for i=1:365
    zz(i)=sum(t_d);
end



for i=1:365
    benefit(i)=zz(i)-CEB(i);
    B=PDB_size(1,i);
    % battery installation cost C1=CB*B+CI;
    %battery degradation cost

    C2=(B*ADR*CE)/BL;%per year Degradation(i)=C2;
    %battery operation cost
    ASL=0.075*B;
    C3=(ACC*CPC)+(ASL*CE);%per year
    C4=B*1*365*0.0005642*0.51;




end
```

```
%pso implementation

[data_final,final_conver] = PSO(PDB_size,no_of_par,no_of_iteration,max_soc,↙ min_soc);% pso loop

[revenue,soc,Total_waste,benefit]=OBJ_BA1(data_final,max_soc,min_soc);   fprintf('\n ************** Case
1:Community Battery ***********************\n');

fprintf('\n Optimal battery size is %d kWh',data_final); fprintf('\n Maximum profit is %d
AUD',revenue);

[hours, days] = meshgrid(1:24, 1:365); figure;
surf(days, hours, soc(1:365,1:24)); axis([1 365 1
24 0 1])
xlabel('Day of the Year');
ylabel('Hour of the Day');
zlabel('soc'); title('Yearly soc');

WsP1=Total_waste{1};
WsP2=Total_waste{2};
WsP3=Total_waste{3};
WsP4=Total_waste{4};
WsP5=Total_waste{5};

for i=1:365
        for ii=1:24
                if isnan(WsP1(i,ii)) WsP1(i,ii)=0;
                end
                if isnan(WsP2(i,ii)) WsP2(i,ii)=0;
                end
                if isnan(WsP3(i,ii)) WsP3(i,ii)=0;
                end
                if isnan(WsP4(i,ii)) WsP4(i,ii)=0;
                end
                if isnan(WsP5(i,ii)) WsP5(i,ii)=0;
                end
        end
end

t_waste=WsP1+WsP2+WsP3+WsP4+WsP5;
fprintf('\n Total surplus power available for Feed in Tariff use')
fprintf('\n Combined surplus Pv power of all houses: %d UNIT',sum(t_waste,'all'));

[hours, days] = meshgrid(1:24, 1:365); figure;
surf(days, hours, WsP1); xlabel('Day of the
Year'); ylabel('Hour of the Day'); zlabel('PV
Power surplus in kW');
title('Yearly Pv surplus power profile House 1');

figure;
surf(days, hours, WsP2); xlabel('Day of the
Year'); ylabel('Hour of the Day'); zlabel('PV
Power surplus in kW');
title('Yearly Pv surplus power profile House 2');

figure;
surf(days, hours, WsP3); xlabel('Day of the
Year'); ylabel('Hour of the Day'); zlabel('PV
```

```
Power surplus in kW');
title('Yearly Pv surplus power profile House 3');

figure;
surf(days, hours, WsP4); xlabel('Day of the
Year'); ylabel('Hour of the Day'); zlabel('PV
Power waste in kW');
title('Yearly Pv Waste profile House 4');

figure;
surf(days, hours, WsP5); xlabel('Day of the
Year'); ylabel('Hour of the Day'); zlabel('PV
Power surplus in kW');
title('Yearly Pv surplus power profile House 5');

  function [x,soc,Total_waste]=OBJ_BA(ba,a,b)

% Yearly LOAD DEMAND of EACH HOUSE
H1=xlsread('DATA.xlsx','H1');
H2=xlsread('DATA.xlsx','H2');
H3=xlsread('DATA.xlsx','H3');
H4=xlsread('DATA.xlsx','H4');
H5=xlsread('DATA.xlsx','H5');

max_soc=a;
min_soc=b;


%PARAMETER SET (TARIFF PRICE 24 hour)
%PARAMETER SET (TARIFF PRICE 24 hour)
%tariff prices in AUD peak_price=0.43;%3pm-
10pm offpeak_price=0.28;%12am-9am
shoulder_price=0.35;%9am-3pm,10pm-12pm


for h=1:24
        if h>14 && h<21 tariff(h)=peak_price;
        elseif (h>7 && h<14) || (h==21)|| (h==22) tariff(h)=shoulder_price;
        else
                tariff(h)=offpeak_price;
        end
```

```
    tariff(25)=offpeak_price;
end

%INTIAL PRICE CALCULATION FOR THE YEAR

% pv+charging loop
cbp1=zeros(365,24);     %     charging     battery     power
cbp2=zeros(365,24);
cbp3=zeros(365,24);
cbp4=zeros(365,24);
cbp5=zeros(365,24);

%yearly Pv generation
PV=xlsread('DATA.xlsx','PV'); size=ba;
soc=zeros(1,25);
soc(1,1)=min_soc;

for i=1:365
    %  House 1 for
    x=1:24; for ii=x
        if(PV(i,ii)>0.02 && PV(i,ii)<H1(i,ii));
            gsp1(i,ii)=H1(i,ii)-PV(i,ii);
            pvsp1(i,ii)=PV(i,ii); ptb1(i,ii)=0;
            bsp1(i,ii)=0; soc(i,ii+1)=soc(i,ii);


        elseif(PV(i,ii)>H1(i,ii) && soc(i,ii)<max_soc); gsp1(i,ii)=0; %grid
            supply power (gsp) pvsp1(i,ii)=H1(i,ii); % PV supply power
            (pvsp)
            ptb1(i,ii)=min(size*(max_soc-soc(i,ii)),PV(i,ii)-H1(i,ii)); % power to↙ battery (ptb)
            cbp1(i,ii)=ptb1(i,ii)+cbp1(i,ii-1); bsp1(i,ii)=0;
            %battery supply power s=ptb1(i,ii)/size;
            soc(i,ii+1)=soc(i,ii)+s;
        else(PV(i,ii)==0 || PV(i,ii)<0.02);
            gsp1(i,ii)=H1(i,ii); pvsp1(i,ii)=0;
            ptb1(i,ii)=0;
            bsp1(i,ii)=0; soc(i,ii+1)=soc(i,ii);

        end
    end
    CBsize_h1(i)=sum(ptb1(i,:));
    %house 2 for
    ii=x
        if(PV(i,ii)>0.02 && PV(i,ii)<H2(i,ii));
            gsp2(i,ii)=H2(i,ii)-PV(i,ii); pvsp2(i,ii)=PV(i,ii);
            ptb2(i,ii)=0;
            bsp2(i,ii)=0; soc(i,ii+1)=soc(i,ii+1);

        elseif(PV(i,ii)>H2(i,ii) && soc(i,ii+1)<max_soc); gsp2(i,ii)=0; %grid
            supply power (gsp) pvsp2(i,ii)=H2(i,ii); % PV supply power
            (pvsp)
            ptb2(i,ii)=min(size*(max_soc-soc(i,ii+1)),PV(i,ii)-H2(i,ii)); % power to↙ battery (ptb)
            cbp2(i,ii)=ptb2(i,ii)+cbp2(i,ii-1); bsp2(i,ii)=0;
            %battery supply power s=ptb2(i,ii)/size;
            soc(i,ii+1)=soc(i,ii+1)+s;
        else(PV(i,ii)==0 || PV(i,ii)<0.02);
            gsp2(i,ii)=H2(i,ii); pvsp2(i,ii)=0;
            ptb2(i,ii)=0;
            bsp2(i,ii)=0; soc(i,ii+1)=soc(i,ii+1);
```

```
    end
end
CBsize_h2(i)=sum(ptb2(i,:));
%house 3
for ii=x
    if(PV(i,ii)>0.02 && PV(i,ii)<H3(i,ii));
        gsp3(i,ii)=H3(i,ii)-PV(i,ii); pvsp3(i,ii)=PV(i,ii);
        ptb3(i,ii)=0;
        bsp3(i,ii)=0; soc(i,ii+1)=soc(i,ii+1);

    elseif(PV(i,ii)>H3(i,ii) && soc(i,ii+1)<max_soc); gsp3(i,ii)=0; %grid
        supply power (gsp) pvsp3(i,ii)=H3(i,ii); % PV supply power
        (pvsp)
        ptb3(i,ii)=min(size*(max_soc-soc(i,ii+1)),PV(i,ii)-H3(i,ii)); % power to↙ battery (ptb)
        cbp3(i,ii)=ptb3(i,ii)+cbp3(i,ii-1); bsp3(i,ii)=0;
        %battery supply power s=ptb3(i,ii)/size;
        soc(i,ii+1)=soc(i,ii+1)+s;
    else(PV(i,ii)==0 || PV(i,ii)<0.02);
        gsp3(i,ii)=H3(i,ii); pvsp3(i,ii)=0;
        ptb3(i,ii)=0;
        bsp3(i,ii)=0; soc(i,ii+1)=soc(i,ii+1);

    end
end
CBsize_h3(i)=sum(ptb3(i,:));
%house 4 for
ii=x
    if(PV(i,ii)>0.02 && PV(i,ii)<H4(i,ii));
        gsp4(i,ii)=H4(i,ii)-PV(i,ii); pvsp4(i,ii)=PV(i,ii);
        ptb4(i,ii)=0;
        bsp4(i,ii)=0; soc(i,ii+1)=soc(i,ii+1);

    elseif(PV(i,ii)>H4(i,ii) && soc(i,ii+1)<max_soc); gsp4(i,ii)=0; %grid
        supply power (gsp) pvsp4(i,ii)=H4(i,ii); % PV supply power
        (pvsp)
        ptb4(i,ii)=min(size*(max_soc-soc(i,ii+1)),PV(i,ii)-H4(i,ii)); % power to↙ battery (ptb)
        cbp4(i,ii)=ptb4(i,ii)+cbp4(i,ii-1); bsp4(i,ii)=0;
        %battery supply power s=ptb4(i,ii)/size;
        soc(i,ii+1)=soc(i,ii+1)+s;
    else(PV(i,ii)==0 || PV(i,ii)<0.02);
        gsp4(i,ii)=H4(i,ii); pvsp4(i,ii)=0;
        ptb4(i,ii)=0;
        bsp4(i,ii)=0; soc(i,ii+1)=soc(i,ii+1);

    end
end
```

```
CBsize_h4(i)=sum(ptb4(i,:));
%house 5 for
ii=x
    if(PV(i,ii)>0.02 && PV(i,ii)<H5(i,ii));
        gsp5(i,ii)=H5(i,ii)-PV(i,ii); pvsp5(i,ii)=PV(i,ii);
        ptb5(i,ii)=0;
        bsp5(i,ii)=0; soc(i,ii+1)=soc(i,ii+1);

    elseif(PV(i,ii)>H5(i,ii) && soc(i,ii+1)<max_soc); gsp5(i,ii)=0; %grid
        supply power (gsp) pvsp5(i,ii)=H5(i,ii); % PV supply power
        (pvsp)
        ptb5(i,ii)=min(size*(max_soc-soc(i,ii+1)),PV(i,ii)-H5(i,ii)); % power to↙ battery (ptb)
        cbp5(i,ii)=ptb5(i,ii)+cbp5(i,ii-1); bsp5(i,ii)=0;
        %battery supply power s=ptb5(i,ii)/size;
        soc(i,ii+1)=soc(i,ii+1)+s;
    else(PV(i,ii)==0 || PV(i,ii)<0.02);
        gsp5(i,ii)=H5(i,ii); pvsp5(i,ii)=0;
        ptb5(i,ii)=0;
        bsp5(i,ii)=0; soc(i,ii+1)=soc(i,ii+1);

    end
end
CBsize_h5(i)=sum(ptb5(i,:)); for ii=x
        if(gsp1(i,ii)>0 && tariff(ii)==peak_price && soc(i,ii+1)>min_soc);
            bsp1(i,ii)=min(size*(soc(i,ii+1)-min_soc),gsp1(i,ii)); bdp1(i,ii)=size*soc(i,ii+1)-
            gsp1(i,ii);

            gsp1(i,ii)=gsp1(i,ii)-bsp1(i,ii);
            soc(i,ii+1)=soc(i,ii+1)-bsp1(i,ii)/ba;
        end


        if(gsp2(i,ii)>0 && tariff(ii)==peak_price && soc(i,ii+1)>min_soc);
            bsp2(i,ii)=min(size*(soc(i,ii+1)-min_soc),gsp2(i,ii)); bdp2(i,ii)=size*soc(i,ii+1)-
            gsp2(i,ii);

            gsp2(i,ii)=gsp2(i,ii)-bsp2(i,ii);
            soc(i,ii+1)=soc(i,ii+1)-bsp2(i,ii)/ba;
        end


        if(gsp3(i,ii)>0 && tariff(ii)==peak_price && soc(i,ii+1)>min_soc);
            bsp3(i,ii)=min(size*(soc(i,ii+1)-min_soc),gsp3(i,ii)); bdp3(i,ii)=size*soc(i,ii+1)-
            gsp3(i,ii);

            gsp3(i,ii)=gsp3(i,ii)-bsp3(i,ii);
            soc(i,ii+1)=soc(i,ii+1)-bsp3(i,ii)/ba;
        end
```

```
            if(gsp4(i,ii)>0 && tariff(ii)==peak_price && soc(i,ii+1)>min_soc);
                bsp4(i,ii)=min(size*(soc(i,ii+1)-min_soc),gsp4(i,ii)); bdp4(i,ii)=size*soc(i,ii+1)-
                gsp4(i,ii);

                gsp4(i,ii)=gsp4(i,ii)-bsp4(i,ii);
                soc(i,ii+1)=soc(i,ii+1)-bsp4(i,ii)/ba;
            end


            if(gsp5(i,ii)>0 && tariff(ii)==peak_price && soc(i,ii+1)>min_soc);
                bsp5(i,ii)=min(size*(soc(i,ii+1)-min_soc),gsp5(i,ii)); bdp5(i,ii)=size*soc(i,ii+1)-
                gsp5(i,ii);

                gsp5(i,ii)=gsp5(i,ii)-bsp5(i,ii);
                soc(i,ii+1)=soc(i,ii+1)-bsp5(i,ii)/ba;
            end
        end

         for ii=x
            if(gsp1(i,ii)>0 && tariff(ii)==shoulder_price && soc(i,ii+1)>min_soc);
                bsp1(i,ii)=min(size*(soc(i,ii+1)-min_soc),gsp1(i,ii)); bdp1(i,ii)=size*soc(i,ii+1)-gsp1(i,ii);

                gsp1(i,ii)=gsp1(i,ii)-bsp1(i,ii);
            end

            if(gsp2(i,ii)>0 && tariff(ii)==shoulder_price && soc(i,ii+1)>min_soc);
                bsp2(i,ii)=min(size*(soc(i,ii+1)-min_soc),gsp2(i,ii)); bdp2(i,ii)=size*soc(i,ii+1)-gsp2(i,ii);

                gsp2(i,ii)=gsp2(i,ii)-bsp2(i,ii);
            end

            if(gsp3(i,ii)>0 && tariff(ii)==shoulder_price && soc(i,ii+1)>min_soc);
                bsp3(i,ii)=min(size*(soc(i,ii+1)-min_soc),gsp3(i,ii)); bdp3(i,ii)=size*soc(i,ii+1)-gsp3(i,ii);

                gsp3(i,ii)=gsp3(i,ii)-bsp3(i,ii);
            end

            if(gsp4(i,ii)>0 && tariff(ii)==shoulder_price && soc(i,ii+1)>min_soc);
                bsp4(i,ii)=min(size*(soc(i,ii+1)-min_soc),gsp4(i,ii)); bdp4(i,ii)=size*soc(i,ii+1)-gsp4(i,ii);

                gsp4(i,ii)=gsp4(i,ii)-bsp4(i,ii);
            end

            if(gsp5(i,ii)>0 && tariff(ii)==shoulder_price && soc(i,ii+1)>min_soc);
                bsp5(i,ii)=min(size*(soc(i,ii+1)-min_soc),gsp5(i,ii)); bdp5(i,ii)=size*soc(i,ii+1)-gsp5(i,ii);

                gsp5(i,ii)=gsp5(i,ii)-bsp5(i,ii);
            end
         end


    end
```

```
    soc(i+1,1)=soc(i,25);
end
%INTIAL PRICE CALCULATION FOR THE YEAR
for i=1:365
    for ii=1:24
        h_h1(i,ii)=(H1(i,ii)-pvsp1(i,ii))*tariff(1,ii);
        h_h2(i,ii)=(H2(i,ii)-pvsp2(i,ii))*tariff(1,ii);
        h_h3(i,ii)=(H3(i,ii)-pvsp3(i,ii))*tariff(1,ii);
        h_h4(i,ii)=(H4(i,ii)-pvsp4(i,ii))*tariff(1,ii);
        h_h5(i,ii)=(H5(i,ii)-pvsp5(i,ii))*tariff(1,ii);
    end d_h1(i)=sum(h_h1(i,:));
    d_h2(i)=sum(h_h2(i,:));
    d_h3(i)=sum(h_h3(i,:));
    d_h4(i)=sum(h_h4(i,:));
    d_h5(i)=sum(h_h5(i,:)); t_d(i)=sum(h_h1(i,:)+h_h2(i,:)+h_h3(i,:)+h_h4(i,:)+h_h5(i,:));



end


CBSP=0.10;% community battery selling poweer price CBBP=0.16;%
Coummunity battery Buying power price

     for i=1:365 for
        ii=1:24

            AC_H1(i,ii)=gsp1(i,ii)*tariff(ii); AC_H2(i,ii)=gsp2(i,ii)*tariff(ii);
            AC_H3(i,ii)=gsp3(i,ii)*tariff(ii); AC_H4(i,ii)=gsp4(i,ii)*tariff(ii);
            AC_H5(i,ii)=gsp5(i,ii)*tariff(ii); sp_H1(i,ii)=CBSP*ptb1(i,ii);
            sp_H2(i,ii)=CBSP*ptb2(i,ii); sp_H3(i,ii)=CBSP*ptb3(i,ii);
            sp_H4(i,ii)=CBSP*ptb4(i,ii); sp_H5(i,ii)=CBSP*ptb5(i,ii);
            BCB_H1(i,ii)=CBBP*bsp1(i,ii); BCB_H2(i,ii)=CBBP*bsp2(i,ii);
            BCB_H3(i,ii)=CBBP*bsp3(i,ii); BCB_H4(i,ii)=CBBP*bsp4(i,ii);
            BCB_H5(i,ii)=CBBP*bsp5(i,ii);
        end
        TAC_H1(i)=sum(AC_H1(i,:));
        TAC_H2(i)=sum(AC_H2(i,:));
        TAC_H3(i)=sum(AC_H3(i,:));
        TAC_H4(i)=sum(AC_H4(i,:));
        TAC_H5(i)=sum(AC_H5(i,:));

     end
     for i=1:365
         TAC_H(i)=sum( AC_H1(i,:)+AC_H2(i,:)+AC_H3(i,:)+AC_H4(i,:)+AC_H5(i,:));
         Tsp_H(i)=sum(sp_H1(i,:)+sp_H1(i,:)+sp_H3(i,:)+sp_H4(i,:)+sp_H5(i,:)); TBCB_H(i)=sum(
         BCB_H1(i,:)+BCB_H2(i,:)+BCB_H3(i,:)+BCB_H4(i,:)+BCB_H5↙
(i,:));
     end
```

```
        CEB=sum(TAC_H)+sum(Tsp_H)-sum(TBCB_H);


for i=1:1
        zz=sum(t_d);
end
benefit=zz-CEB;
co=benefit;
CB=500;% CB=per unit battery cost x=co-
(ba*CB/10);

% total PV power wasted by each house and total WsP1=PV-
pvsp1-ptb1;
WsP2=PV-pvsp2-ptb2;
WsP3=PV-pvsp3-ptb3;
WsP4=PV-pvsp4-ptb4;
WsP5=PV-pvsp5-ptb5;

Total_waste{1}=WsP1;
Total_waste{2}=WsP2;
Total_waste{3}=WsP3;
Total_waste{4}=WsP4;
Total_waste{5}=WsP5;
end

function [x,soc,Total_waste,benefit]=OBJ_BA1(ba,a,b)

% Yearly LOAD DEMAND of EACH HOUSE
H1=xlsread('DATA.xlsx','H1');
H2=xlsread('DATA.xlsx','H2');
H3=xlsread('DATA.xlsx','H3');
H4=xlsread('DATA.xlsx','H4');
H5=xlsread('DATA.xlsx','H5');

max_soc=a;
min_soc=b;

%PARAMETER SET (TARIFF PRICE 24 hour)
%tariff prices in AUD peak_price=0.45;%3pm-
10pm offpeak_price=0.28;%12am-9am
shoulder_price=0.35;%9am-3pm,10pm-12pm


for h=1:24
        if h>14 && h<21 tariff(h)=peak_price;
        elseif (h>7 && h<14) || (h==21)|| (h==22) tariff(h)=shoulder_price;
        else
                tariff(h)=offpeak_price;
        end
        tariff(25)=offpeak_price;
end
```

```
% pv+charging loop
cbp1=zeros(365,24);    %    charging    battery    power
cbp2=zeros(365,24);
cbp3=zeros(365,24);
cbp4=zeros(365,24);
cbp5=zeros(365,24);


%yearly Pv generation
PV=xlsread('DATA.xlsx','PV'); size=ba;
soc=zeros(1,25);
soc(1,1)=min_soc;

for i=1:365
    %  House 1 for
    x=1:24; for ii=x
        if(PV(i,ii)>0.02 && PV(i,ii)<H1(i,ii));
            gsp1(i,ii)=H1(i,ii)-PV(i,ii); pvsp1(i,ii)=PV(i,ii);
            ptb1(i,ii)=0;
            bsp1(i,ii)=0; soc(i,ii+1)=soc(i,ii);


        elseif(PV(i,ii)>H1(i,ii) && soc(i,ii)<max_soc); gsp1(i,ii)=0; %grid
            supply power (gsp) pvsp1(i,ii)=H1(i,ii); % PV supply power
            (pvsp)
            ptb1(i,ii)=min(size*(max_soc-soc(i,ii)),PV(i,ii)-H1(i,ii)); % power to↙ battery (ptb)
            cbp1(i,ii)=ptb1(i,ii)+cbp1(i,ii-1); bsp1(i,ii)=0;
            %battery supply power s=ptb1(i,ii)/size;
            soc(i,ii+1)=soc(i,ii)+s;
        else(PV(i,ii)==0 || PV(i,ii)<0.02);
            gsp1(i,ii)=H1(i,ii); pvsp1(i,ii)=0;
            ptb1(i,ii)=0;
            bsp1(i,ii)=0; soc(i,ii+1)=soc(i,ii);

        end
    end
    CBsize_h1(i)=sum(ptb1(i,:));
    %house 2 for
    ii=x
        if(PV(i,ii)>0.02 && PV(i,ii)<H2(i,ii));
            gsp2(i,ii)=H2(i,ii)-PV(i,ii); pvsp2(i,ii)=PV(i,ii);
            ptb2(i,ii)=0;
            bsp2(i,ii)=0;
```

```
        soc(i,ii+1)=soc(i,ii+1);

    elseif(PV(i,ii)>H2(i,ii) && soc(i,ii+1)<max_soc); gsp2(i,ii)=0; %grid
        supply power (gsp) pvsp2(i,ii)=H2(i,ii); % PV supply power
        (pvsp)
        ptb2(i,ii)=min(size*(max_soc-soc(i,ii+1)),PV(i,ii)-H2(i,ii)); % power to↙ battery (ptb)
        cbp2(i,ii)=ptb2(i,ii)+cbp2(i,ii-1); bsp2(i,ii)=0;
        %battery supply power s=ptb2(i,ii)/size;
        soc(i,ii+1)=soc(i,ii+1)+s;
    else(PV(i,ii)==0 || PV(i,ii)<0.02);
        gsp2(i,ii)=H2(i,ii); pvsp2(i,ii)=0;
        ptb2(i,ii)=0;
        bsp2(i,ii)=0; soc(i,ii+1)=soc(i,ii+1);

    end
end
CBsize_h2(i)=sum(ptb2(i,:));
%house 3 for
ii=x
    if(PV(i,ii)>0.02 && PV(i,ii)<H3(i,ii));
        gsp3(i,ii)=H3(i,ii)-PV(i,ii); pvsp3(i,ii)=PV(i,ii);
        ptb3(i,ii)=0;
        bsp3(i,ii)=0; soc(i,ii+1)=soc(i,ii+1);

    elseif(PV(i,ii)>H3(i,ii) && soc(i,ii+1)<max_soc); gsp3(i,ii)=0; %grid
        supply power (gsp) pvsp3(i,ii)=H3(i,ii); % PV supply power
        (pvsp)
        ptb3(i,ii)=min(size*(max_soc-soc(i,ii+1)),PV(i,ii)-H3(i,ii)); % power to↙ battery (ptb)
        cbp3(i,ii)=ptb3(i,ii)+cbp3(i,ii-1); bsp3(i,ii)=0;
        %battery supply power s=ptb3(i,ii)/size;
        soc(i,ii+1)=soc(i,ii+1)+s;
    else(PV(i,ii)==0 || PV(i,ii)<0.02);
        gsp3(i,ii)=H3(i,ii); pvsp3(i,ii)=0;
        ptb3(i,ii)=0;
        bsp3(i,ii)=0; soc(i,ii+1)=soc(i,ii+1);

    end
end
CBsize_h3(i)=sum(ptb3(i,:));
%house 4 for
ii=x
    if(PV(i,ii)>0.02 && PV(i,ii)<H4(i,ii));
        gsp4(i,ii)=H4(i,ii)-PV(i,ii); pvsp4(i,ii)=PV(i,ii);
```

```
        ptb4(i,ii)=0;
        bsp4(i,ii)=0; soc(i,ii+1)=soc(i,ii+1);

    elseif(PV(i,ii)>H4(i,ii) && soc(i,ii+1)<max_soc); gsp4(i,ii)=0; %grid
        supply power (gsp) pvsp4(i,ii)=H4(i,ii); % PV supply power
        (pvsp)
        ptb4(i,ii)=min(size*(max_soc-soc(i,ii+1)),PV(i,ii)-H4(i,ii)); % power to↙ battery (ptb)
        cbp4(i,ii)=ptb4(i,ii)+cbp4(i,ii-1); bsp4(i,ii)=0;
        %battery supply power s=ptb4(i,ii)/size;
        soc(i,ii+1)=soc(i,ii+1)+s;
    else(PV(i,ii)==0 || PV(i,ii)<0.02);
        gsp4(i,ii)=H4(i,ii); pvsp4(i,ii)=0;
        ptb4(i,ii)=0;
        bsp4(i,ii)=0; soc(i,ii+1)=soc(i,ii+1);

    end
end
CBsize_h4(i)=sum(ptb4(i,:));
%house 5 for
ii=x
    if(PV(i,ii)>0.02 && PV(i,ii)<H5(i,ii));
        gsp5(i,ii)=H5(i,ii)-PV(i,ii); pvsp5(i,ii)=PV(i,ii);
        ptb5(i,ii)=0;
        bsp5(i,ii)=0; soc(i,ii+1)=soc(i,ii+1);

    elseif(PV(i,ii)>H5(i,ii) && soc(i,ii+1)<max_soc); gsp5(i,ii)=0; %grid
        supply power (gsp) pvsp5(i,ii)=H5(i,ii); % PV supply power
        (pvsp)
        ptb5(i,ii)=min(size*(max_soc-soc(i,ii+1)),PV(i,ii)-H5(i,ii)); % power to↙ battery (ptb)
        cbp5(i,ii)=ptb5(i,ii)+cbp5(i,ii-1); bsp5(i,ii)=0;
        %battery supply power s=ptb5(i,ii)/size;
        soc(i,ii+1)=soc(i,ii+1)+s;
    else(PV(i,ii)==0 || PV(i,ii)<0.02);
        gsp5(i,ii)=H5(i,ii); pvsp5(i,ii)=0;
        ptb5(i,ii)=0;
        bsp5(i,ii)=0; soc(i,ii+1)=soc(i,ii+1);

    end
end
CBsize_h5(i)=sum(ptb5(i,:)); for ii=x
        if(gsp1(i,ii)>0 && tariff(ii)==peak_price && soc(i,ii+1)>min_soc);
            bsp1(i,ii)=min(size*(soc(i,ii+1)-min_soc),gsp1(i,ii));
```

```
            bdp1(i,ii)=size*soc(i,ii+1)-gsp1(i,ii);

            gsp1(i,ii)=gsp1(i,ii)-bsp1(i,ii);
            soc(i,ii+1)=soc(i,ii+1)-bsp1(i,ii)/ba;
        end
        if(gsp2(i,ii)>0 && tariff(ii)==peak_price && soc(i,ii+1)>min_soc);
            bsp2(i,ii)=min(size*(soc(i,ii+1)-min_soc),gsp2(i,ii)); bdp2(i,ii)=size*soc(i,ii+1)-
            gsp2(i,ii);

            gsp2(i,ii)=gsp2(i,ii)-bsp2(i,ii);
            soc(i,ii+1)=soc(i,ii+1)-bsp2(i,ii)/ba;
        end

        if(gsp3(i,ii)>0 && tariff(ii)==peak_price && soc(i,ii+1)>min_soc);
            bsp3(i,ii)=min(size*(soc(i,ii+1)-min_soc),gsp3(i,ii)); bdp3(i,ii)=size*soc(i,ii+1)-
            gsp3(i,ii);

            gsp3(i,ii)=gsp3(i,ii)-bsp3(i,ii);
            soc(i,ii+1)=soc(i,ii+1)-bsp3(i,ii)/ba;
        end

        if(gsp4(i,ii)>0 && tariff(ii)==peak_price && soc(i,ii+1)>min_soc);
            bsp4(i,ii)=min(size*(soc(i,ii+1)-min_soc),gsp4(i,ii)); bdp4(i,ii)=size*soc(i,ii+1)-
            gsp4(i,ii);

            gsp4(i,ii)=gsp4(i,ii)-bsp4(i,ii);
            soc(i,ii+1)=soc(i,ii+1)-bsp4(i,ii)/ba;
        end

        if(gsp5(i,ii)>0 && tariff(ii)==peak_price && soc(i,ii+1)>min_soc)
            bsp5(i,ii)=min(size*(soc(i,ii+1)-min_soc),gsp5(i,ii)); bdp5(i,ii)=size*soc(i,ii+1)-
            gsp5(i,ii);

            gsp5(i,ii)=gsp5(i,ii)-bsp5(i,ii);
            soc(i,ii+1)=soc(i,ii+1)-bsp5(i,ii)/ba;
        end
    end
      for ii=x
        if(gsp1(i,ii)>0 && tariff(ii)==shoulder_price && soc(i,ii+1)>min_soc);
            bsp1(i,ii)=min(size*(soc(i,ii+1)-min_soc),gsp1(i,ii)); bdp1(i,ii)=size*soc(i,ii+1)-gsp1(i,ii);

            gsp1(i,ii)=gsp1(i,ii)-bsp1(i,ii);
        end

        if(gsp2(i,ii)>0 && tariff(ii)==shoulder_price && soc(i,ii+1)>min_soc);
            bsp2(i,ii)=min(size*(soc(i,ii+1)-min_soc),gsp2(i,ii)); bdp2(i,ii)=size*soc(i,ii+1)-gsp2(i,ii);

            gsp2(i,ii)=gsp2(i,ii)-bsp2(i,ii);
        end

        if(gsp3(i,ii)>0 && tariff(ii)==shoulder_price && soc(i,ii+1)>min_soc);
            bsp3(i,ii)=min(size*(soc(i,ii+1)-min_soc),gsp3(i,ii));
```

```
                              bdp3(i,ii)=size*soc(i,ii+1)-gsp3(i,ii);

                              gsp3(i,ii)=gsp3(i,ii)-bsp3(i,ii);
                        end

                        if(gsp4(i,ii)>0 && tariff(ii)==shoulder_price && soc(i,ii+1)>min_soc);
                              bsp4(i,ii)=min(size*(soc(i,ii+1)-min_soc),gsp4(i,ii)); bdp4(i,ii)=size*soc(i,ii+1)-gsp4(i,ii);

                              gsp4(i,ii)=gsp4(i,ii)-bsp4(i,ii);
                        end

                        if(gsp5(i,ii)>0 && tariff(ii)==shoulder_price && soc(i,ii+1)>min_soc);
                              bsp5(i,ii)=min(size*(soc(i,ii+1)-min_soc),gsp5(i,ii)); bdp5(i,ii)=size*soc(i,ii+1)-gsp5(i,ii);

                              gsp5(i,ii)=gsp5(i,ii)-bsp5(i,ii);
                        end
                  end


      end soc(i+1,1)=soc(i,25);

end


%INTIAL PRICE CALCULATION FOR THE YEAR
for i=1:365
      for ii=1:24
            h_h1(i,ii)=(H1(i,ii)-pvsp1(i,ii))*tariff(1,ii);
            h_h2(i,ii)=(H2(i,ii)-pvsp2(i,ii))*tariff(1,ii);
            h_h3(i,ii)=(H3(i,ii)-pvsp3(i,ii))*tariff(1,ii);
            h_h4(i,ii)=(H4(i,ii)-pvsp4(i,ii))*tariff(1,ii);
            h_h5(i,ii)=(H5(i,ii)-pvsp5(i,ii))*tariff(1,ii);
      end d_h1(i)=sum(h_h1(i,:));
      d_h2(i)=sum(h_h2(i,:));
      d_h3(i)=sum(h_h3(i,:));
      d_h4(i)=sum(h_h4(i,:));
      d_h5(i)=sum(h_h5(i,:)); t_d(i)=sum(h_h1(i,:)+h_h2(i,:)+h_h3(i,:)+h_h4(i,:)+h_h5(i,:));


end


CBSP=0.10;% community battery selling poweer price CBBP=0.16;%
Coummunity battery Buying power price

       for i=1:365 for
            ii=1:24

                  AC_H1(i,ii)=gsp1(i,ii)*tariff(ii); AC_H2(i,ii)=gsp2(i,ii)*tariff(ii);
                  AC_H3(i,ii)=gsp3(i,ii)*tariff(ii); AC_H4(i,ii)=gsp4(i,ii)*tariff(ii);
                  AC_H5(i,ii)=gsp5(i,ii)*tariff(ii); sp_H1(i,ii)=CBSP*ptb1(i,ii);
                  sp_H2(i,ii)=CBSP*ptb2(i,ii);
```

```
                    sp_H3(i,ii)=CBSP*ptb3(i,ii); sp_H4(i,ii)=CBSP*ptb4(i,ii);
                    sp_H5(i,ii)=CBSP*ptb5(i,ii); BCB_H1(i,ii)=CBBP*bsp1(i,ii);
                    BCB_H2(i,ii)=CBBP*bsp2(i,ii); BCB_H3(i,ii)=CBBP*bsp3(i,ii);
                    BCB_H4(i,ii)=CBBP*bsp4(i,ii); BCB_H5(i,ii)=CBBP*bsp5(i,ii);
                end
                TAC_H1(i)=sum(AC_H1(i,:));
                TAC_H2(i)=sum(AC_H2(i,:));
                TAC_H3(i)=sum(AC_H3(i,:));
                TAC_H4(i)=sum(AC_H4(i,:));
                TAC_H5(i)=sum(AC_H5(i,:));

          end
          for i=1:365
                TAC_H(i)=sum( AC_H1(i,:)+AC_H2(i,:)+AC_H3(i,:)+AC_H4(i,:)+AC_H5(i,:));
                Tsp_H(i)=sum(sp_H1(i,:)+sp_H1(i,:)+sp_H3(i,:)+sp_H4(i,:)+sp_H5(i,:)); TBCB_H(i)=sum(
                BCB_H1(i,:)+BCB_H2(i,:)+BCB_H3(i,:)+BCB_H4(i,:)+BCB_H5↙
(i,:));
          end
        CEB=sum(TAC_H)+sum(Tsp_H)-sum(TBCB_H);


for i=1:1
        zz=sum(t_d);
end
benefit=zz-CEB;
co=benefit;
CB=500;% CB=per unit battery cost x=co-
(ba*CB/10);

% total PV power wasted by each house and total WsP1=PV-
pvsp1-ptb1;
WsP2=PV-pvsp2-ptb2;
WsP3=PV-pvsp3-ptb3;
WsP4=PV-pvsp4-ptb4;
WsP5=PV-pvsp5-ptb5;

Total_waste{1}=WsP1;
Total_waste{2}=WsP2;
Total_waste{3}=WsP3;
Total_waste{4}=WsP4;
Total_waste{5}=WsP5;
end

%PSO
function [data_final,final_conver] = PSO(PDB_size,no_of_par,no_of_iteration,a,b);


% PSO parameters
numParticles =no_of_par;                    % Number of particles
maxIter =no_of_iteration;                          % Maximum number of iterations
```

```
w = 0.5;                              % Inertia weight
c1 = 1.5;                             % Cognitive (personal) acceleration coefficient
c2 = 1.5;                             % Social (global) acceleration coefficient
minBatterySize = min(PDB_size);                  % Minimum battery size
maxBatterySize = max(PDB_size);                  % Maximum battery size


% Initialize the particles
particlePosition = minBatterySize + (maxBatterySize - minBatterySize) * rand↙ (numParticles, 1);
particleVelocity = zeros(numParticles, 1); personalBestPosition
= particlePosition; personalBestCost = zeros(numParticles, 1);

% Evaluate initial personal best costs for i =
1:numParticles
    personalBestCost(i) = OBJ_BA(particlePosition(i),a,b);
end

% Initialize the global best
[globalBestCost, bestIdx] = max(personalBestCost); globalBestPosition =
personalBestPosition(bestIdx);

% PSO main loop
for iter = 1:maxIter
    % Update the velocity and position of each particle for i =
    1:numParticles
        r1 = rand; r2
        = rand;
        particleVelocity(i) = w * particleVelocity(i) ...
                                  + c1 * r1 * (personalBestPosition(i) - particlePosition↙
(i)) ...
                                  + c2 * r2 * (globalBestPosition - particlePosition(i)); particlePosition(i) =
        particlePosition(i) + particleVelocity(i);
        % Check bounds
        if particlePosition(i) < minBatterySize particlePosition(i) = minBatterySize;
        elseif particlePosition(i) > maxBatterySize particlePosition(i) =
            maxBatterySize;
        end

        % Evaluate the cost function
        currentCost = OBJ_BA(particlePosition(i),a,b);

        % Update personal best
        if currentCost > personalBestCost(i) personalBestCost(i) =
            currentCost; personalBestPosition(i) = particlePosition(i);
        end
    end

    % Update global best
```

```
          [currentBestCost, bestIdx] =
          max(personalBestCost); if currentBestCost >
          globalBestCost
                    globalBestCost = currentBestCost;
                    globalBestPosition =
                    personalBestPosition(bestIdx);

          end
          bestCostHistory(iter) = globalBestCost;
          fprintf('Iteration %d: Best Cost = %.4f\n', iter, globalBestCost);

end

data_final=round(globalBestPosit
ion);
final_conver=globalBestCost;

% Plot the iteration vs cost function graph
figure;
plot(1:maxIter, bestCostHistory, 'LineWidth', 2);
xlabel('Iteration');
ylabel('Best Cost');
title('Iteration vs. Best
Cost'); grid on;


%net present value
calculation
Intial_cost=CB*B+CI;
%yearly cash flow
C2=(B*ADR*CE)/BL;%per
year
Degradation(i)=C2;
ASL=0.075*B;
C3=(ACC*CPC)+(ASL*CE);%per
year C4=B*1*365*0.0005642*0.51;
cash_flow=benefit+grid_sell_price*sum(t_waste,'all')+C4-C2-C3;



summ=0;
for i=1:period
          summ=summ+(cash_flow/((1+I_r)
          ^i));
end
NPVC1=summ-Intial_cost;

fprintf('\n The net present value after 10 years is : %d AUD',NPVC1);
```