ASSESTMENT OF COOPERATION OF PHOTOVOLTAICS AND ELECTRIFIED MICRO MOBILITY IN THE CONCEPT OF NET ZERO ENERGY CITIES

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ABSTRACT

ASSESMENT OF COOPERATION OF PHOTOVOLTAICS AND ELECTRIFIED MICRO MOBILITY IN THE CONCEPT OF NET ZERO ENERGY CITIES

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In today's world, the majority of energy generation still relies on non-renewable sources such as coal and oil. To reduce the dependence on these non-renewables, Battery Energy Storage Systems (BESS) and photovoltaics present a viable solution. Rooftop photovoltaics, for example, can help avoid congestion in the transmission system and support the charging of micro-mobility devices, which represent the next phase of public transportation. Additionally, they can contribute to reducing building energy consumption within the net-zero energy framework. However, since photovoltaic generation and energy demand do not always align, BESS is necessary to store excess energy, and its effective operation requires a control algorithm to maximize benefits. The key to such investments lies in their feasibility and control, as both rooftop photovoltaics and BESS have limited lifespans and are costly technologies. This thesis will evaluate the integration of micro-mobility and photovoltaics in the pursuit of net-zero energy cities, using a rule-based controller for a system composed of photovoltaic panels (PVs), electric vehicles (EVs), loads, and BESS. Controlling the charging and discharging schedule of the BESS is crucial for optimizing its

performance. By the conclusion of this thesis, the goal is to provide an assessment of micro-mobility and PV integration, and to propose an off-the-shelf solution that requires no location-specific configuration.

Keywords: Battery Energy Storage System, Electric Vehicle, Photovoltaic Systems

ÖZ

FOTOVOLTAİK VE ELEKTRİKLENDİRİLMİŞ MİKRO MOBİLİTENİN NET SIFIR ENERJİ ŞEHİRLER KAPSAMINDA İŞ BİRLİĞİNİN DEĞERLENDİRİLMESİ

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Günümüzde enerji üretiminin büyük bir kısmı hala kömür ve petrol gibi yenilenemeyen kaynaklara dayanıyor. Bu yenilenemeyen kaynaklara olan bağımlılığı azaltmak için Batarya Enerji Depolama Sistemleri (BESS) ve fotovoltaikler (PV) uygun bir çözüm sunuyor. Örneğin, çatı üstü fotovoltaikler, iletim sistemindeki tıkanıklığı önlemeye yardımcı olabilir ve bir sonraki toplu taşıma aşaması olan mikro-mobilite cihazlarının şarjını destekleyebilir. Ayrıca, net-sıfır enerji çerçevesinde bina enerji tüketimini azaltmaya katkıda bulunabilirler. Ancak, fotovoltaik üretim ile enerji talebi her zaman örtüşmediğinden, fazla enerjiyi depolamak için BESS gereklidir ve bu sistemin etkin çalışması, faydaların en üst düzeye çıkarılması için bir kontrol algoritması gerektirir. Bu tür yatırımların anahtarı hem çatı üstü fotovoltaikler hem de BESS in sınırlı ömrü ve maliyetli teknolojiler olması nedeniyle, fizibilite ve kontrolünde yatmaktadır. Bu tez, mikro-mobilite ve fotovoltaiklerin net-sıfır enerji şehirleri hedefinde entegrasyonunu değerlendirecek ve fotovoltaik paneller (PV), elektrikli araçlar (EV), yükler ve BESS ten oluşan bir sistem için kural tabanlı bir kontrolör kullanacaktır. BESS in şarj ve deşarj programını kontrol etmek, performansını optimize etmek için kritik öneme sahiptir. Bu tezin sonunda, mikro-mobilite ve PV entegrasyonuna dair bir değerlendirme sunmak ve konum bazlı bir yapılandırma gerektirmeyen bir çözüm önermek hedeflenmektedir.

Anahtar Kelimeler: Batarya Enerji Depolama Sistemi, Elektrikli Araç, Fotovoltaik Sistem

To My Beloved Family,

Alper Aydınalp

Elif Aydınalp

Nur Aydınalp

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CHAPTER 1

INTRODUCTION

Climate change led the governments provide incentives for the utilization of clean energy. Among the economically and technically feasible clean energy resources, the solar energy stands out, because of the decreasing unit price of photovoltaics (PV) based systems, as well as the possibility of locating those systems even on rooftops.

The distributed energy resource allocation has been encouraged in the las couple of decades. However, In Holland, as of 2022, because of the difference between the generation location (residential rooftops) and the electrical load demand (industrial regions), the transmission grid experiences congestion, which hardens the operation. Figure 1 shows the congestion within Holland. Therefore, for reliable and sustainable operation, and reduced losses, rather than an uncoordinated distributed energy generation, a net-zero energy concept, which aims to consume the generated electrical energy at the generation location, has been encouraged and suggested by academia and authorities.

A net-zero energy building in the current context, indicates that the building should generate just as much clean energy as it would consume, and therefore there is absolutely no need for emission of any greenhouse gases (GHGs) into the environment directly or indirectly.

With respect to the current regulation in Türkiye, to help realizing Net-Zero Energy buildings, supplying electricity to the grid does not create any additional income to the system (building) operator. Since the regulation forces to use generated electricity, it is desired to use them at the generation time, locally.

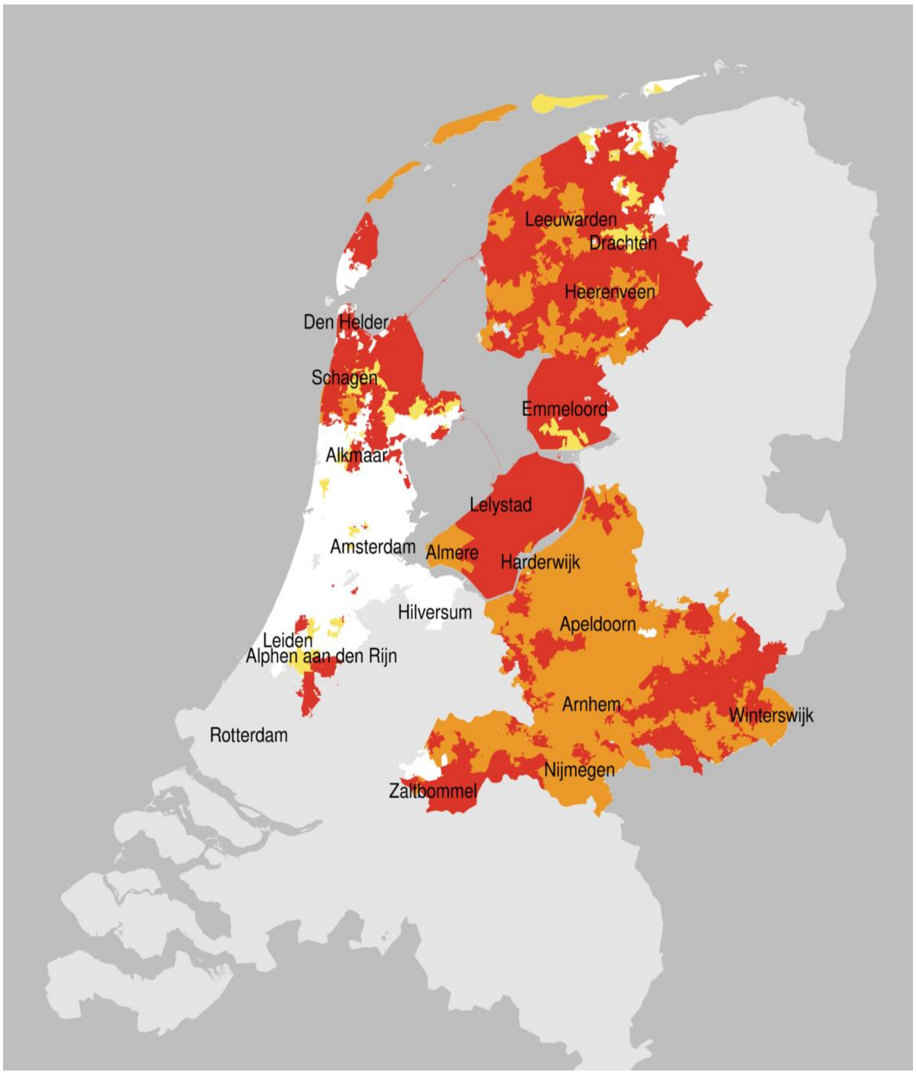

Figure 1 Congestion within Holland [1]

Considering the regulations and benefits of the Net-Zero Energy Buildings, generation within the city, where consumption occurs, is required. For achieving Net-Zero Energy Buildings and avoid congestion within the transmission grid, rooftop PVs offer the most feasible solution since they are easy to implement and operate, as those systems can be installed on roof-tops. The major problem to achieve Net-Zero Energy

Buildings especially at the residential regions is the fact that solar power generation profile and electrical demand profile of those regions are non-conforming as seen in Figure 2. Therefore, additional electrical loads and energy storage should be considered.

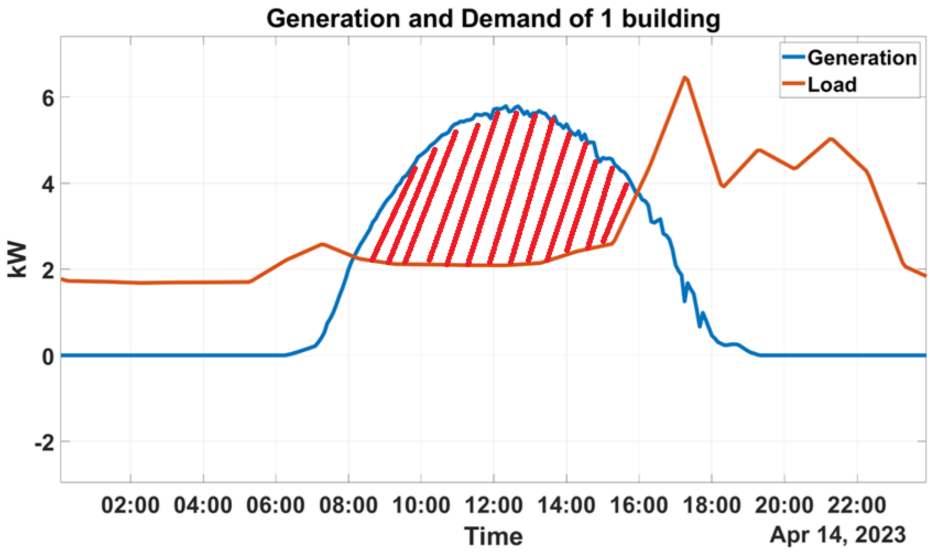

Figure 2 Generation and Demand of a Residential Building

From the transportation perspective, most common GHG emission is the usage of fossil fuels in combustion motor engine. In the transportation sector, public transportation vehicles such as buses which utilizes combustion motors effects carbon emission significantly. A significant contributor to global warming is greenhouse gases mainly made up of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

To reduce the carbon emission within the sector, use of electrified micro-mobility options, as e-bikes and e-scooters, offers an environmentally friendly solution. However, charging and electrification of those systems are not zero-emission approaches. In order to charge the devices, trucks are being utilized for the purpose of transporting the battery to a charging facility when there is little to no demand.

The usage of rooftop PVs not only creates a solution for congestion but also can be utilized for the concept of micro-mobility charging. As seen Figure 2, there exists a surplus energy generated by PV systems, because of the difference between the power generation profile and load profile of residential and commercial energy users.

Since there are surplus electricity throughout the day, this surplus electricity can be used for environmental issues within a community such as the charging of shared micro-mobility devices in a local manner.

The motivation behind this thesis is to achieve Net-Zero Energy Buildings with the inclusion of rooftop photovoltaics to reduce both the carbon emission of the trucks that are being utilized for the charging of shared micro-mobility devices and the possibility of congestion in the transmission system. As seen from Figure 2, the surplus electricity can be used for the charging of the shared micro-mobility devices and if there is still excess, there should be a utilization of BESS for the reduction of building demand in the current concept.

1.1 Net-Zero Energy Cities/ Buildings

Buildings are the number one source of greenhouse gas emissions and since the Paris agreement their electricity consumption are trying to be decreased. The Net-Zero Energy Buildings (NZEBs) can be explained as the reduced electricity consumption of a regular building. In order to achieve that it is essential to install Distributed Energy Resources such as PVs to reduce the consumption from the grid. In literature it has been proposed to implement a Battery Energy Storage System (BESS) to further decrease the greenhouse gas emissions [1]. Fossil fuel plants are the most contributing factor to greenhouse gas emissions and thus global warming [1], [2] and since awareness on global warming is increasing rapidly the usage of DERs are rapidly increasing as well [1], [2].

The disadvantage of DERs are their intermittent characteristics. Since they highly depend on weather conditions, they cannot uninterruptedly supply the demand inside a building, to mitigate this issue, utilising BESSs have been proposed [1], [2], [3] ,[4].

In literature there have been multiple proposals on how a net-zero energy building can be built. Multiple research studies [3], [5], [6] proposed to have a highly insulated building with PV panels where solar radiation is high. In [4] it has been proposed to have both wind turbines and PV panels to achieve Net-Zero Energy Buildings. All of them have their advantages in the road of achieving Net-Zero but a significant disadvantage of all options is the cost of installation.

The technologies that have been presented in the literature include solar-wind and battery combinations [7], solar-fuel cell combination [8] and wind-battery combinations [9], since easiest of them to implement is solar-battery combination it has been a developing configuration. All of the above have the same goal of reduction of electricity consumption which is the main objective of NZEBs.

1.2 Micro-mobility

Micro-mobility is a developing and a promising option for urban transport within the scope of NZEBs and Net-Zero Energy Cities (NZECs). They can be considered common in urban areas and have significant impacts on United Nations Sustainable Development Goals (SDGs) [10]. The main SDGs that micro-mobility contributes are namely good health and well-being, sustainable cities and communities, responsible consumption and production, and climate action [10].

The fast increase in fossil fuel utilization resulted in global warming [11], [12] and to alter this direction usage of DERs such as waste heat recovery [13], [14], fuel cells [15], [16], [17], solar PV [18], geothermal [19], [20], and usage of biomass energies [21], [22], [23], have been implemented. To further decrease the GHG emissions, micro-mobility concept has been introduced.

The advantage of micro-mobility is the flexibility and sustainability that it provides [24]. The devices that can be used in micro-mobility are bicycles, scooters and skateboards also, these vehicles can be used either privately owned or shared [25].

Shared micro-mobility is a constantly growing industry with private companies. These companies use shared micro-mobility devices such as scooters and bicycles. Within the concept of urban planning, micro-mobility solutions are utilized by means of public transport. Since micro-mobility devices are fully dependent on electricity, they do not emit GHGs which coincides with the goals of the Paris agreement. However, the challenge behind this concept is the charging of the empty battery. The charging of batteries is done by collecting them by a truck and transporting them to a charging facility in which the batteries are charged while the demand for the devices is the lowest which corresponds to night. This not only creates pollution because of the lack of usage for electrified trucks, but also is an extra investment for the company. These are one of the core motivations behind this thesis as it is aimed to provide NZECs by reducing the GHG emissions and the consumption from the grid as the grid is still dependent on non-renewable energy sources such as coal and natural gas.

1.3 Photovoltaic Panels

As the technologies start to improve the cost starts to decrease as they are negatively correlated with each other. In today's world installing a PV panel to a rooftop has an incremental cost of 97 United States Dollars [26] per meter square (USD/m2 or $/m2) but as new technologies emerge this cost is expected to go down. However, as the technology is still developing, the price is considered as expensive.

In Türkiye, the solar industry is rapidly increasing, according to the TEİAŞ activity report in 2023, the solar generation went up from 16887.6 GWh to 18726.8 GWh with a 10.9% increase. It is one of the most rapidly and steadily increasing technology in today's world. The generation pie graph within the world for 2010 and 2023 are given in Figure 3 and 4.

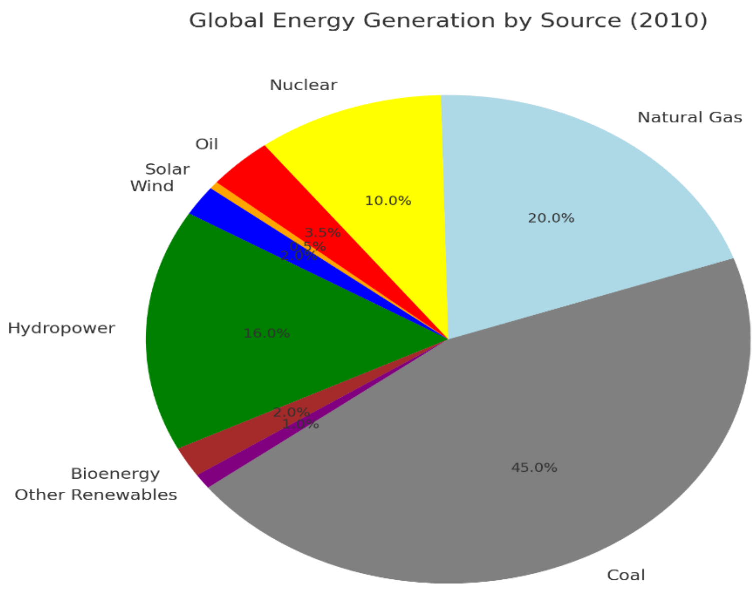

Figure 3 Distribution of energy generation for 2010

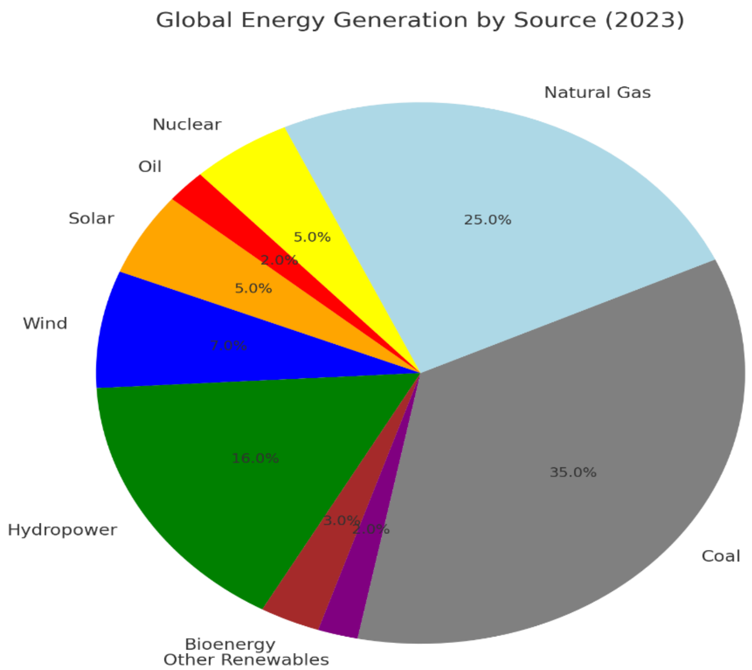

Figure 4 Distribution of energy generation in Türkiye for 2023

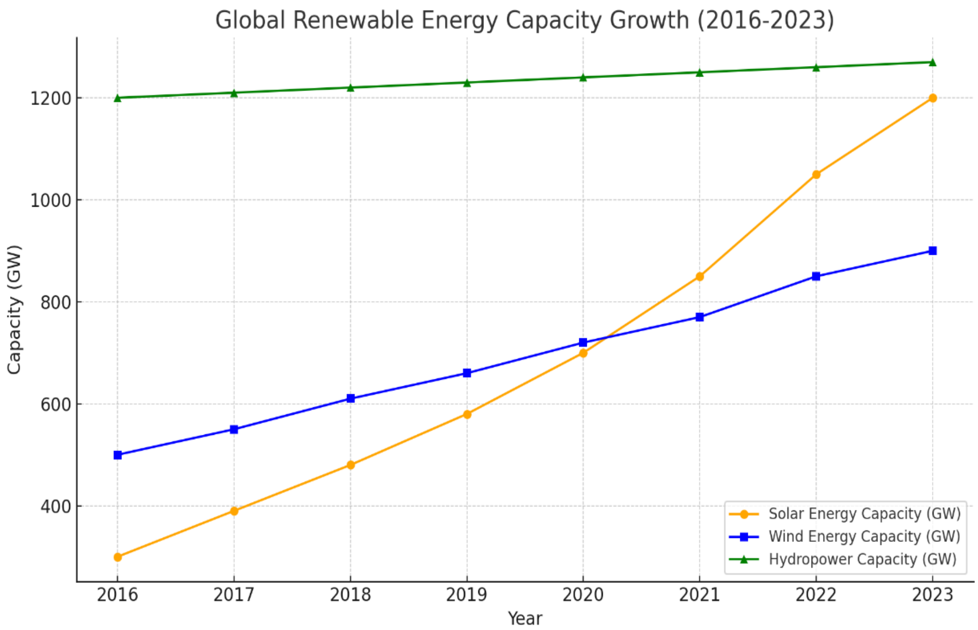

Figure 5 Yearly Capacity Growth of Renewables

Distributed energy resources (DERs) such as PVs are starting to be used not only for electric demand but also for micro-mobility charging issues. PVs that are planning to be built upon the rooftop of existing buildings not only avoids any congestion within the transmission network but most importantly it also reduces the need for a truck to charge empty micro-mobility device battery.

Operation of trucks can be considered as environmentally dangerous as trucks mostly still do not use electricity, so they emit GHGs. That is why DERs play an important role in reducing the carbon footprint not only on residential purposes but also in transportation industry. However, the intermittent characteristic of PV panels is a major issue within the charging of micro-mobility devices. The uncertainty is directly linked to the weather parameters which can change based on the seasonality. Normalized generation profiles for one day in each quarter of one year is given from Figures 6 to 9.

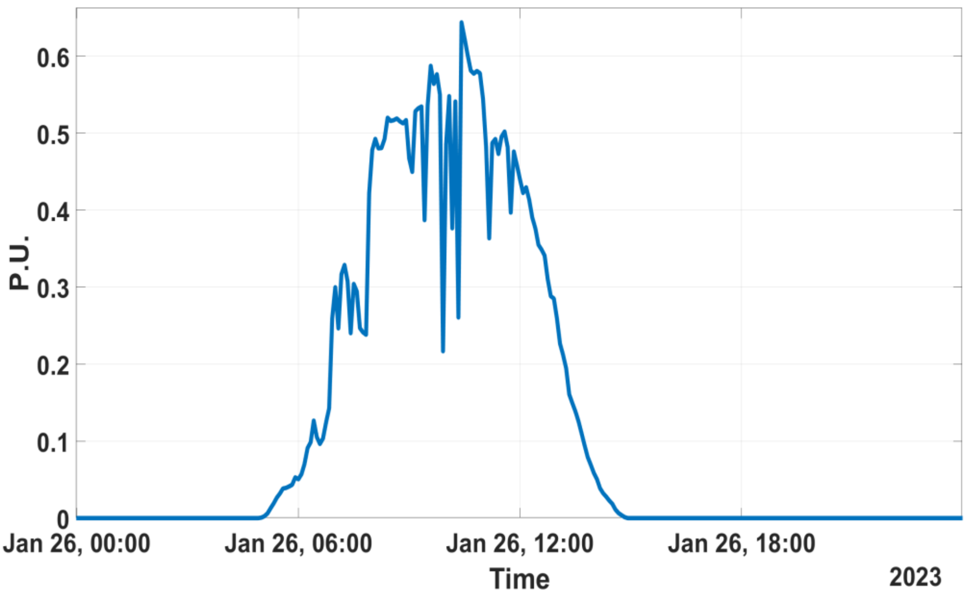

Figure 6 Normalized Generation for January 26

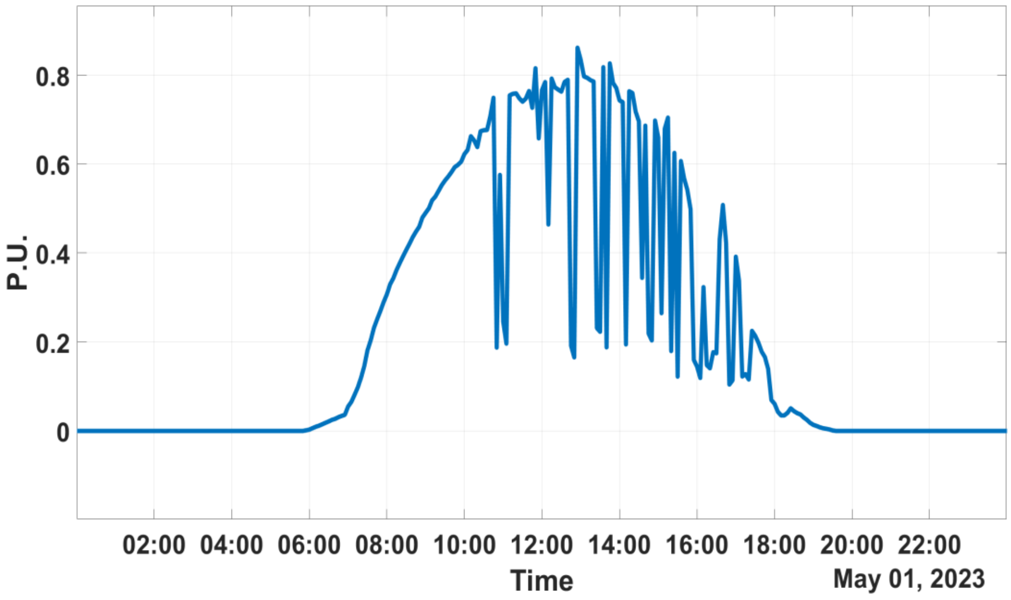

Figure 7 Normalized Generation for May 1

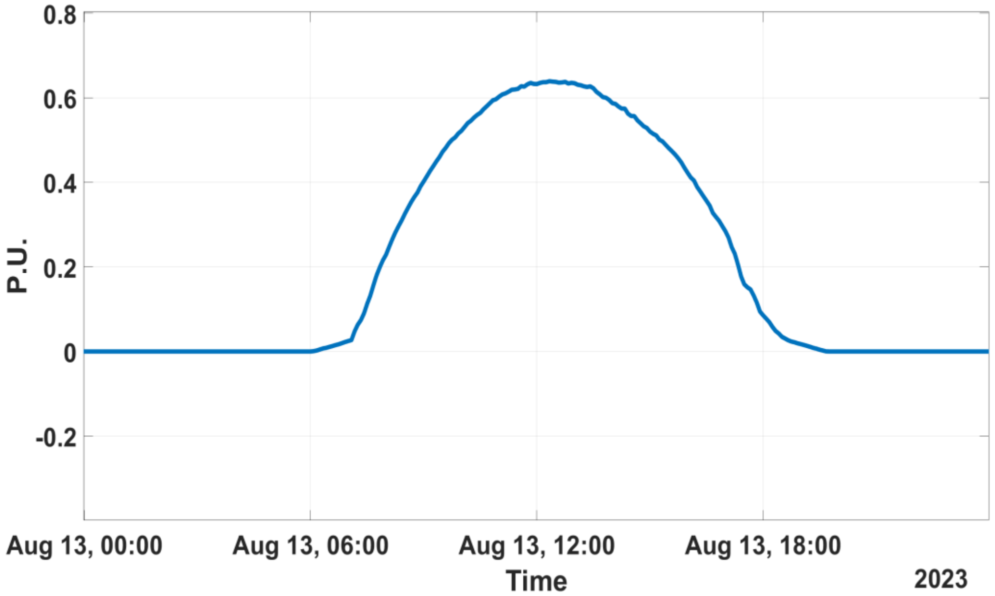

Figure 8 Normalized Generation for August 13

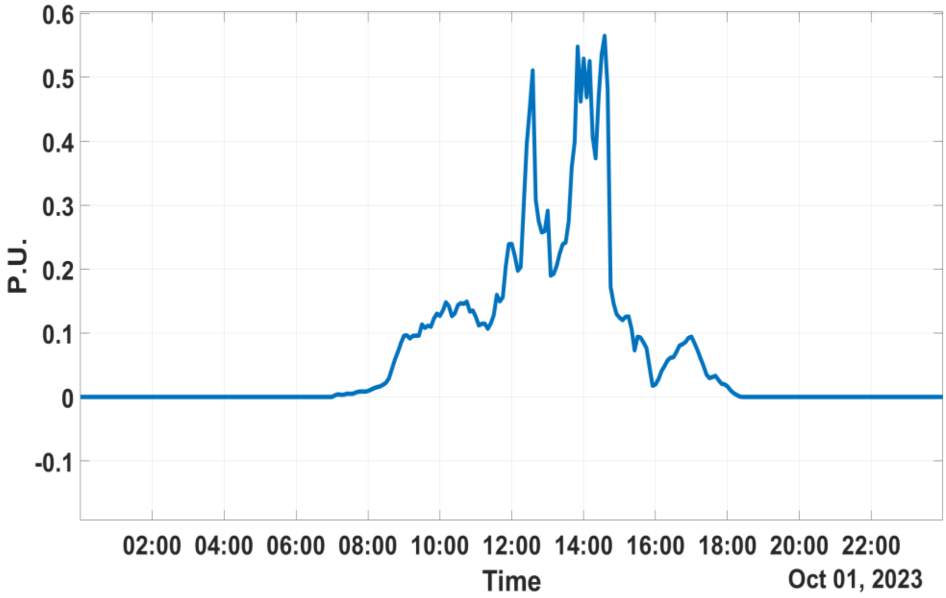

Figure 9 Normalized Generation for October 1

Figure 6 corresponds to 26th of January. For these months, it can be seen that the PV generation starts relatively late at 9 o'clock and has a disturbed shape because of the rainy and snowy weather.

In Figure 7, it can be seen that the generation is much more of a sine wave shape as the seasonal rains come to an end but there are still spikes and crests as cloudiness also effects the generation significantly.

Figure 8 can be considered as the optimal case since the generation starts to increase around 07:00 AM and has somewhat smooth curve which occurs during most summer days and months.

Figure 9 represents the daily normalized generation of 1st of October. As expected, the generation significantly changed as snow rain and cloudiness increased drastically.

The uncertain characteristics of the PV generation is a major issue while supplying the load from the building and the demand from the EVs. For this purpose, battery energy storage systems (BESSs) are being utilized.

1.4 Battery Energy Storage Systems

The main usage of BESS is for demand side management (DSM) purposes. The main goal of utilizing a BESS is to shave the peak demand by the excess electricity throughout the day as seen from Figure 10. With this kind of approach, it is aimed to create a more constant load curve in order to increase stability of the grid.

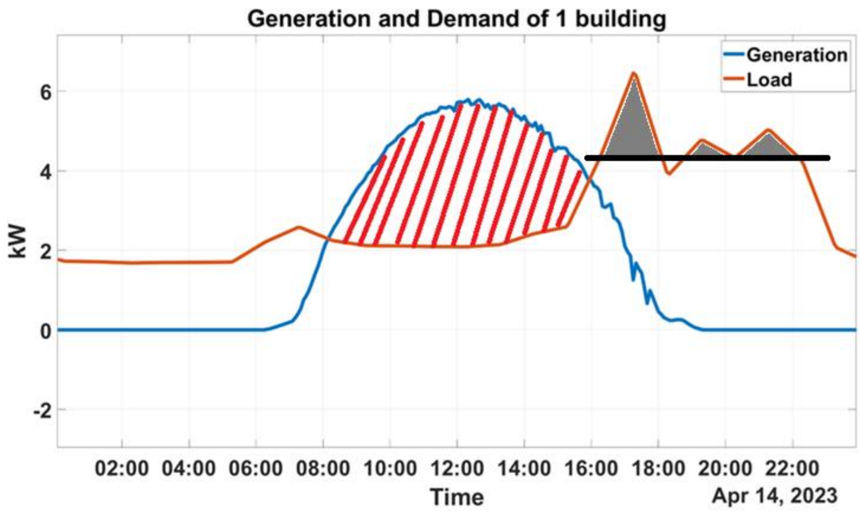

Figure 10 Peak Shaving Illustration

The only possible way to achieve such goals is offered by chemical BESSs. People looked for a way to store electricity to use it later on, the first battery was made possible with the finding of electrostatic effects and storage devices [28]. There are mainly 2 types of BESS technology. Those are irreversible and reversible. The difference between the two types are their anode and cathode materials. Based on the chemical reactions chosen, between cathode and anode with a conducting medium, a battery can be made chargeable. Chargeable batteries are industrialized because of the flexibility and multiple use properties however single use batteries are still being used for appliances.

As the utilization of PV panels are increasing rapidly, since the peak demand in Türkiye occurs after or near sunset, the need to store the excess electricity throughout the day also emerges.

The intermittent characteristics of renewables and the concern for global warming are the main effect on the increase of the BESS utilization however since the battery industry is still developing, it has an expensive incremental cost of 400$ per kWh [27]. As the technologies start to improve, this cost is estimated to be reduced. The investment cost of such a battery might be expensive so it is important to conduct a feasibility analysis before implementing such device. The increase in usage of BESS throughout the years is given in Figure 11.

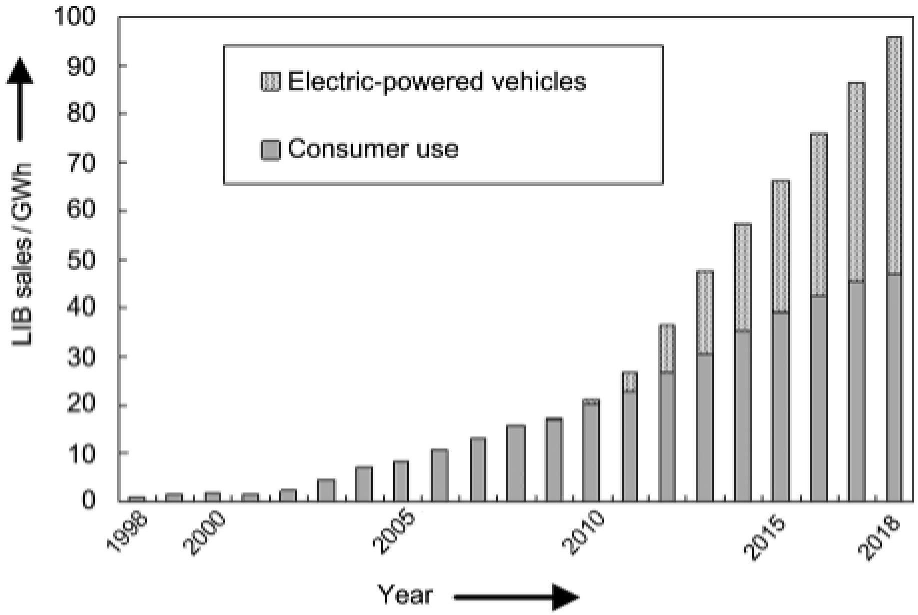

Figure 11 Usage of BESS according to the years [29].

As the BESS is still developing, it has a limited lifetime and still an expensive device. Because of these reasons, there should be a control mechanism to prolong the lifetime of the BESS. The chemical reactions inside the battery are the main factor that reduces the battery lifetime. It has been demonstrated in [30] that rapid BESS power switching creates micro-cracks inside the BESS which reduces the lifetime of the BESS significantly.

Role of the battery in the motivation behind this thesis is the flexibility and control of the overall system. It not only creates a load but also can be source of energy when necessary. To mitigate the intermittent characteristics of PVs the battery SoC is to be controlled to supply or demand electricity when needed in the concept of achieving NZECs.

1.5 Control methods in NZEBs:

To achieve NZEBs, it is desired to use PVs and BESSs since generation of PVs and load are not conforming with each other. If only PVs were to be used there was no need for a control mechanism however the disadvantage of such system occurs when generation is not present. This time of the year and day there would be no reduction in the electricity consumption of the building which is against net-zero principle. To mitigate this issue BESSs should be utilized which requires a control mechanism to schedule charging and discharging for the purpose of increasing the resiliency of the system and prolonging its lifetime.

There are multiple energy management control methods while utilising DERs and BESSs within a net-zero building [31]. These can be optimization-based control strategies, hierarchical and rule-based control strategies. The optimization-based control strategies offer global minimum of the objective function which can include various functions such as cost of utilization, greenhouse gas emissions, profitability and so on but it brings a huge computational burden and also another disadvantage of optimization-based EM is the need for configuration for different geographical location [31]. Since optimization techniques need historical data for training purposes, it needs new data for each geographical location. These optimization techniques can be Convex Optimization (CO), Swarm Optimization, Matheuristics and Fuzzy Optimization.

In [32] CO has been used to minimize the daily cost of operation and smoothing the exchange of power between the utility and microgrid. In [33] it has been proposed to use CO to optimize power dispatching and it has been solved using sub-gradient method.

In [34] a three-level control architecture has been proposed to implement multiple objectives. For the first level a decentralized virtual BESS based droop control has been used and an improved Particle Swarm Optimization (PSO) has been utilised to obtain BESS parameters. In [35] PSO has been used to optimize each agent within a multi agent system considering each DER and the economical need of the system.

Matheuristic methods are the combination of mathematical and heuristic optimization methods. This idea is still developing and recent, but it is being used in vehicle routing and wind farm configuration problems [36], [37], [38]. In [36] a 3-class differentiation for matheuristic methods have been presented and those are decomposition, which divides the problem into sub-problems with specific solution method for each, improvement, which improves the solution found by a heuristic method with mathematical programming and finally Branch-and-price/column generation-based approach which uses set portioning formulation in which binary values. In [37] a backtracking search algorithm (BSA) has been proposed in the power systems area and in [38] a matheuristic method for emergency response for contingency planning has been proposed. The optimization criteria in the method is the reduction of cost of non-supplied energy and the penalties for important customers as well as electrical constraints such as Kirchoff voltage and current laws.

In EMS area it has been proposed in [39] to use matheuristic optimization to handle emergency response to faults. A heuristic method has been used for the prioritization of loads and Mixed Integer Linear Programming (MILP) which is a mathematical method is used to solve the optimization problem.

Fuzzy optimization is an optimization technique which includes uncertainties and utilizes logical reasoning to solve the problem. The major advantage of Fuzzy logic optimization is the flexibility. Reference [40] provides a microgrid with Fuzzy logic optimization to consider different SoC ranges within the BESS. Also, in [41] a microgrid control is achieved by neuro-fuzzy wavelet-based controller which has been utilized in power converters.

Another control technique which can be used is the hierarchical control method which is divided into three areas. Primary, secondary and tertiary control.

The aim of primary control is to control inverter output and power output by using droop or non-droop-based methods. It is the fastest control mechanism and voltage as well as power balance control is achieved in this step [42], [43]. Droop based control methods are widely being used in industry however they have major disadvantages such as [44]:

- Poor transient response due to using rated power levels.
- Performance issues stemming from ignoring load dynamics.
- Strong interaction between active and reactive power due to a low X/R ratio.
- Stability concerns resulting from load harmonics.

In literature, some research studies have been conducted to mitigate these disadvantages [45], [46].

To continue, changes in voltage magnitude and frequency are corrected in the secondary control which can be made with centralized, decentralized and distributed control methods. Some basic advantages and disadvantages of these control methods are given in Table 1 [47], [48], [49], [50].

Table 1 Advantages and Disadvantages of Secondary Control Methods

Type	Advantages	Disadvantages
Centralized Control	Simpler to implement Easier control algorithms Effective at global optimal	Heavy computational burden
Decentralized Control	Low communication burden Most inexpensive method	Cannot guarantee optimal operating point
Distributed Control	Redundancy and robustness Better suited for cyber-attacks	Most expensive option

Apart from the optimization-based and hierarchical energy management techniques, rule-based control offers an easier implementation and a real-time control of the system which does not include any configuration specific to the geographical location. The major difference between optimization-based and rule-based techniques is the achievement of global optimum.

Chu Sun et al. [50] proposed a rule-based control approach as a microgrid controller. The technique keeps a constant BESS SoC around 50% to increase the reliability and lifetime of the BESS and in [51] it has been proposed a similar rule-based approach and the control rules are created by the imbalance between load and renewable generation.
In [52] S. Manson et al. propose a BESS based control technique for power smoothing and in [53] load following control and cycle-charging control have been compared. Bo Zhao et al. [54] presents a hybrid adaptive rule-based dispatch such as [50] however the goals are not achieved in [54].

Since rule-based control approach is easy to implement and does not require historical data for training purposes, in this thesis rule-based control architecture will be implemented.

1.6 Problem Definition

This thesis explores the integration of rooftop photovoltaic (PV) systems with shared micro-mobility networks, focusing on utilizing surplus energy from PV generation to charge micro-mobility devices. These devices, which are accessible to the public within a defined region, can be picked up and dropped off at various substations. While the operation of this micro-mobility network is assumed to be managed by a company using mobile applications, the thesis emphasizes its integration and feasibility into a PV and BESS framework to support the concept of NZECs while financial and operational conditions are out of the scope.

By leveraging surplus PV energy and employing a rule-based controller to efficiently manage the charging and discharging of the BESS, this approach examines the feasibility of storing excess energy and optimizing its usage. The study aims to demonstrate how this integration can contribute to the realization of NZECs, aligning with sustainability goals and energy efficiency principles.

By applying a BESS and rooftop PVs, it is aimed to maximize the benefit for the building end-user, micro-mobility operator and micro-mobility user by investigating the feasibility of the system using a rule-based control architecture since optimization-based control techniques need geographical configuration of the controller and is difficult to implement.

In this thesis, real-time control actions of a system consisting of loads, photovoltaic generation units, battery energy storage system, conventional electrical grid and finally electric vehicles will be mimicked by a rule-based controller.

The main objectives of this thesis are presented below:

1. Assessment of cooperation of rooftop PVs and shared micro-mobility for the concept of NZECs
2. Optimizing the microgrid's operating cost during grid-connected mode in the presence of rooftop PVs, EVs, BESS and multi-directional grid connection,
3. Providing an off the shelf product that can be utilized globally.

1.7 Thesis outline

In this thesis, the work is presented within five chapters. The formation of the thesis is as follows,

The first chapter is the introduction behind this thesis. A literature review on NZECs and NZEBs, micro-mobility, the evolution of photovoltaics, battery energy storage systems and control methods in a NZEBs are presented.

In the second chapter, the modelling micro-mobility, residential and commercial loads, and PV generation will be presented. To continue, the implementation of PVs and micro-mobility and loads will be evaluated.

Since there will be a battery utilization there will be a control architecture. The developed rule-based controller is broached in the third chapter and the logic behind the controller is introduced. There are two controller schemes that will be presented. Difference between two developed controller is the inclusion of seasonality effect while controlling the SoC of the BESS. Within this controller it is aimed to provide a commercial behaviour for the BESS.

The simulation scenarios will be explained first, followed by an assessment of the system, with the results from the rule-based controller's utilization presented and discussed in Chapter 4.

In conclusion, which is the fifth chapter, the goal and achievement of this thesis will be given. Along with that, future work and areas to improve will be explained.

CHAPTER 2

SYSTEM MODELLING

This chapter will evaluate the implementation of the micro-mobility devices, residential and non-residential loads and PV generation which are the first step of the thesis. Figure 12 provides the considered system configuration.

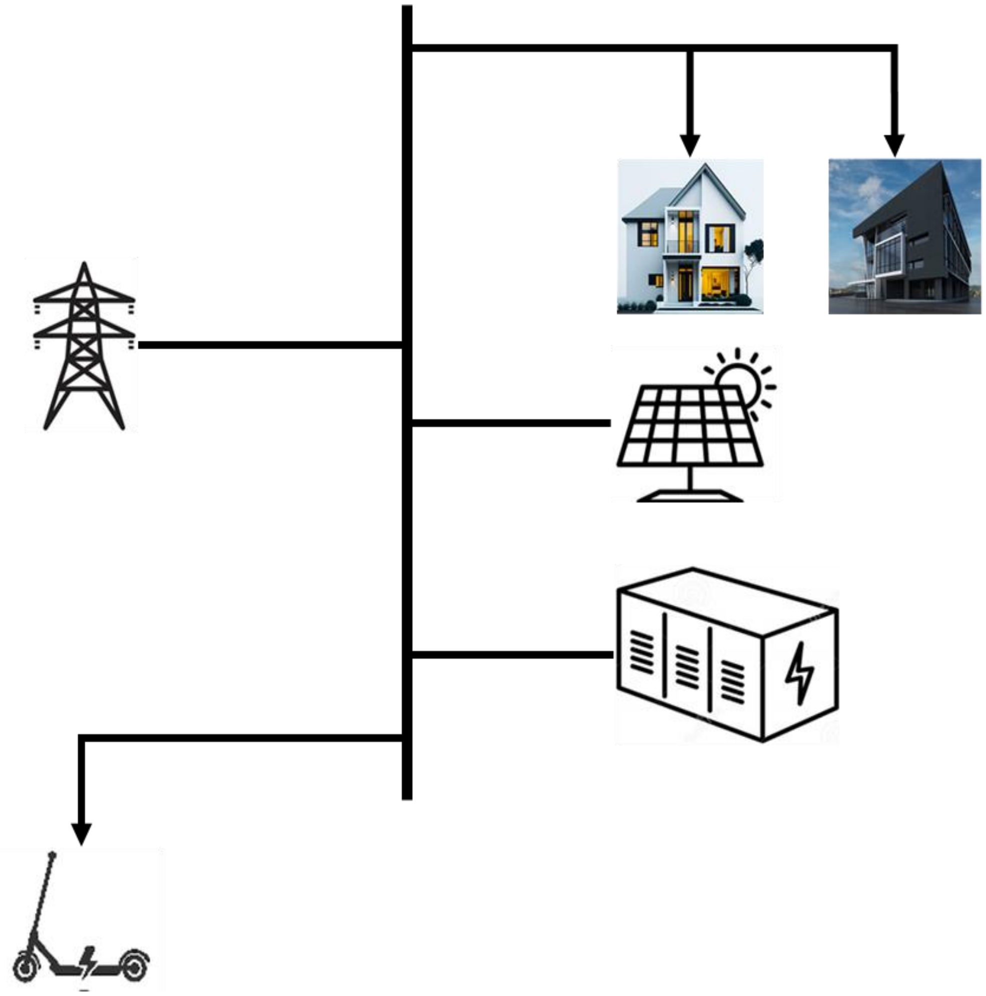

Figure 12 Considered System Structure

In order to model the behaviour of a selected region there is a need for a yearly data for the system components that needs modelling such as micro-mobility usage, residential and non-residential loads and PV generation for the sole purpose of representing year-long behaviour.

The yearly characteristic of PV generation is completely based on real data since PV generation is directly correlated with solar irradiation and by using the stored irradiation data from the selected region, for different PVs yearly generation profile has been created.

To continue, since micro-mobility and loads are directly related to socioeconomic and personal behaviours, also since the selected region involves a large amount of these components, it is infeasible to model them individually by collecting real data. For these reasons, modelling for these components are required.

2.1 PV Generation Modelling

In this thesis, photovoltaic (PV) generation has been simulated using collected solar radiation data from the selected region, adjusted by applying appropriate constants to create a realistic yearly generation profile.

According to regulations [55], the peak generation capacity in kilowatts should align with the peak demand over a one-year period. However, because PV units do not generate power always ideally in practice, the installed capacity typically needs to exceed peak demand. For the purposes of this thesis, it is assumed that the PV units are ideally placed, disregarding the azimuth angle of the rooftops, allowing the installed PV capacity to match peak demand exactly. Figure 13 shows the normalized solar radiation profile for the first week of January.

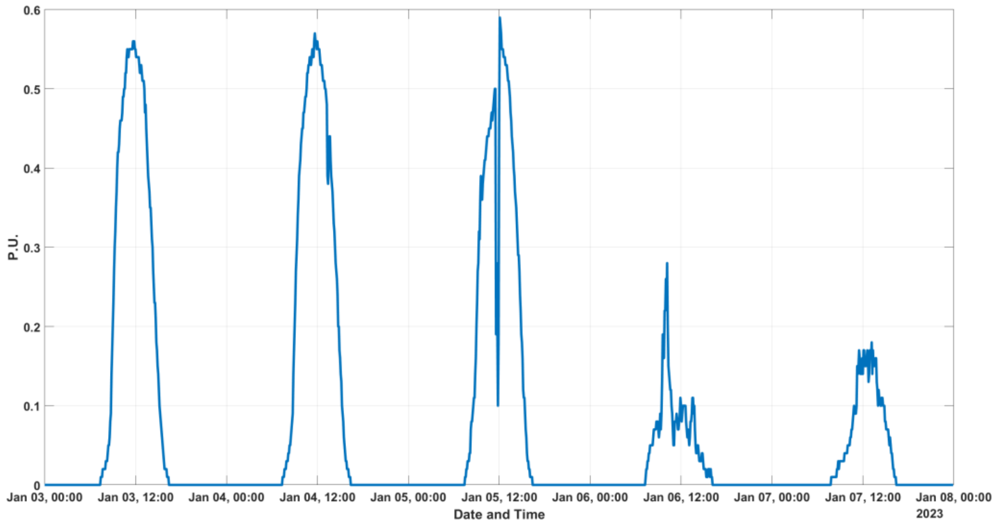

Figure 13 Normalized Solar Radiation for January 3 to January 7

2.2 Micro-Mobility Modelling

In Figure 14 the normalized usage profile of the micro-mobility device based on the seasonality has been given.

This extra load on top of the building load creates a higher load level throughout the day which ultimately will reduce the ROI value because it decreases the amount of BESS capacity needed to store the excess electricity. Also, another reason why higher loads reduce the ROI is the amount of decrease in the electricity bill during peak time tariff. Since the decrease in terms of Turkish Liras (TLs) is much higher than a regular building with no EVs it is expected to have a higher profit which leads to a lower ROI value.

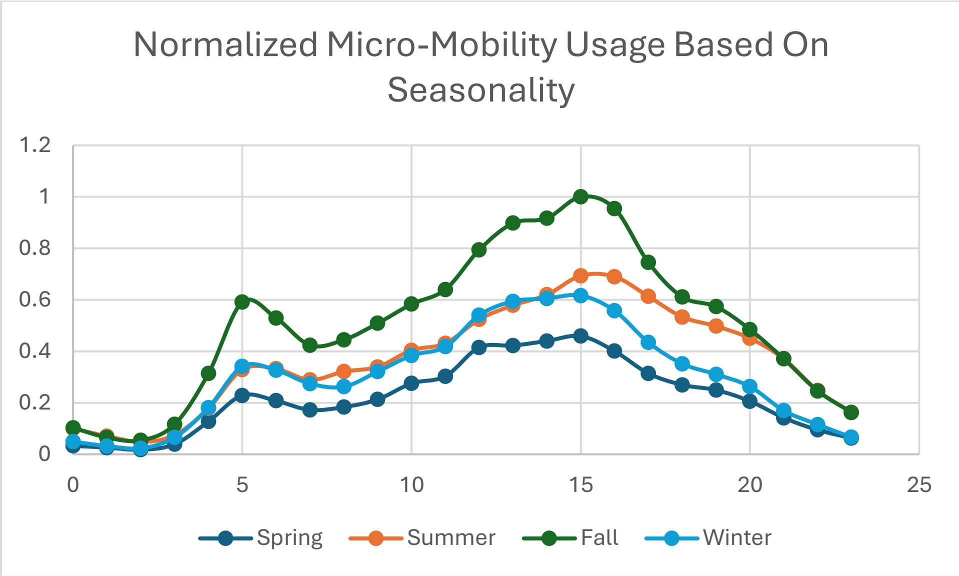

Figure 14 Normalized Usage of EVs

The general usage profile can be interpreted logically. The fact that the consumption increases after 4 AM is the result of using EVs for school and work. After 08:00 AM it gradually increases until 04:00 PM and that is the time when peak demand occurs because the EVs are often used after school by teenagers.

Based on the seasonality, as expected, the usage profile may have changed drastically. The highest utilization of e-scooters may occur in the fall, which could be due to the fact that schools have started, and weather conditions like rain and snow may not yet have begun, especially since the selected region is near the coast.

The second most used time of the year might be summer. This could be attributed to humidity and temperature during the day. While there may still be a local peak near 5 AM, it might not be as significant as in the fall since much of the working class may have left the city for holidays and vacations. When temperatures start to decrease after 2 PM, peak usage may occur.

Winter could be the second least used season. This may suggest that usage still occurs due to schools being in session, but it might not be as much as in the fall due to colder weather conditions, such as low temperatures and snow. However, it could also be observed that during the hottest hours of the day, around 12 PM and 1 PM, usage may be higher than during the summer.

The least used seasons may be spring and winter, as rainy days could dominate the season, and people might avoid using micro-mobility devices due to the possibility of getting wet.

The daily usage of micro-mobility devices for each season on Monday, Friday, Saturday, and Sunday may be illustrated in Figures 15 to 18.

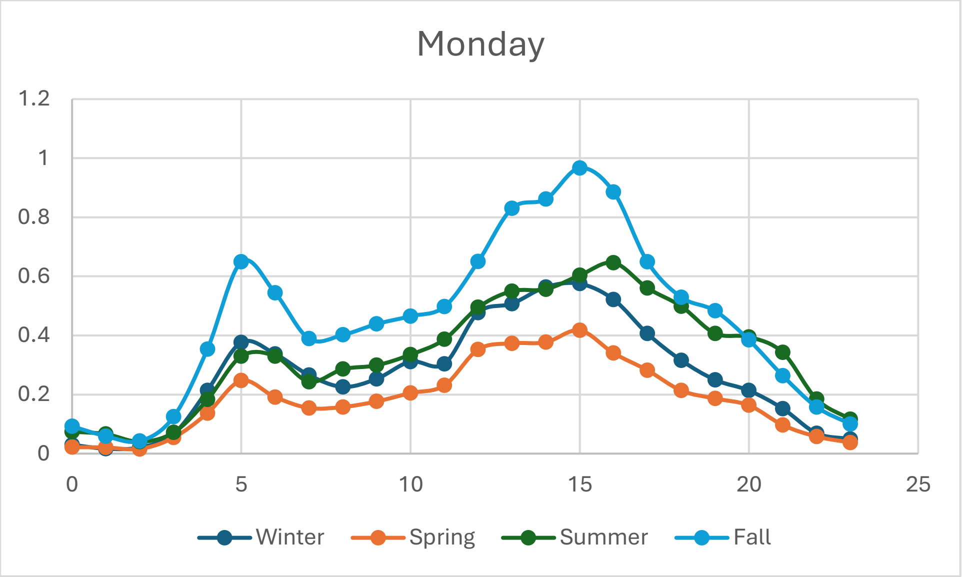

Figure 15 Hourly Normalized Usage of Monday for Each Season

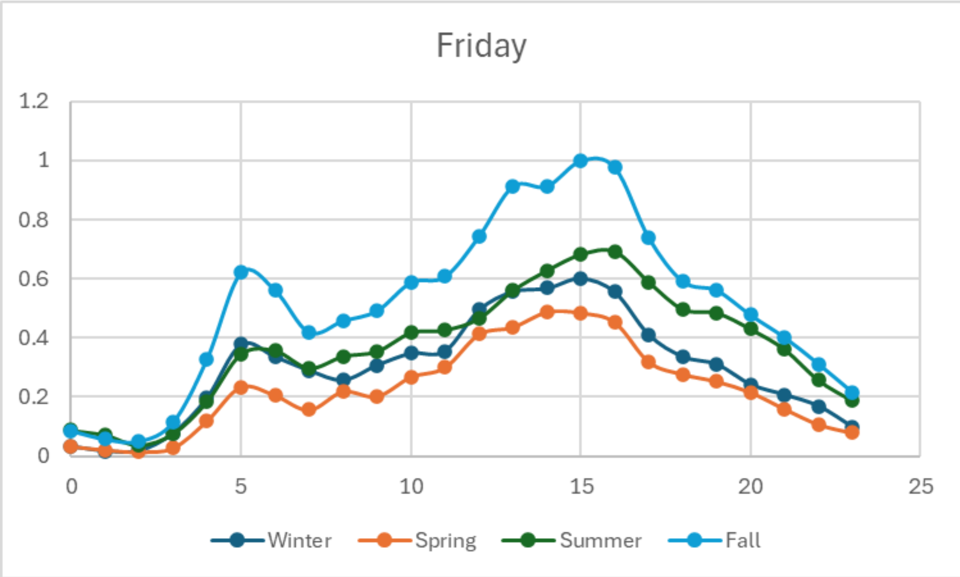

Figure 16 Hourly Normalized Usage of Friday for Each Season

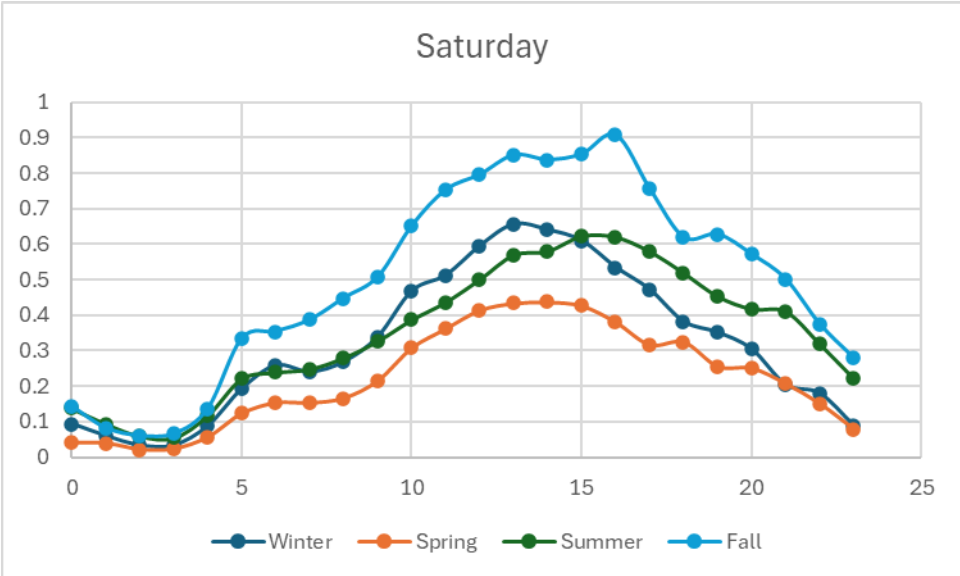

Figure 17 Hourly Normalized Usage of Saturday for Each Season

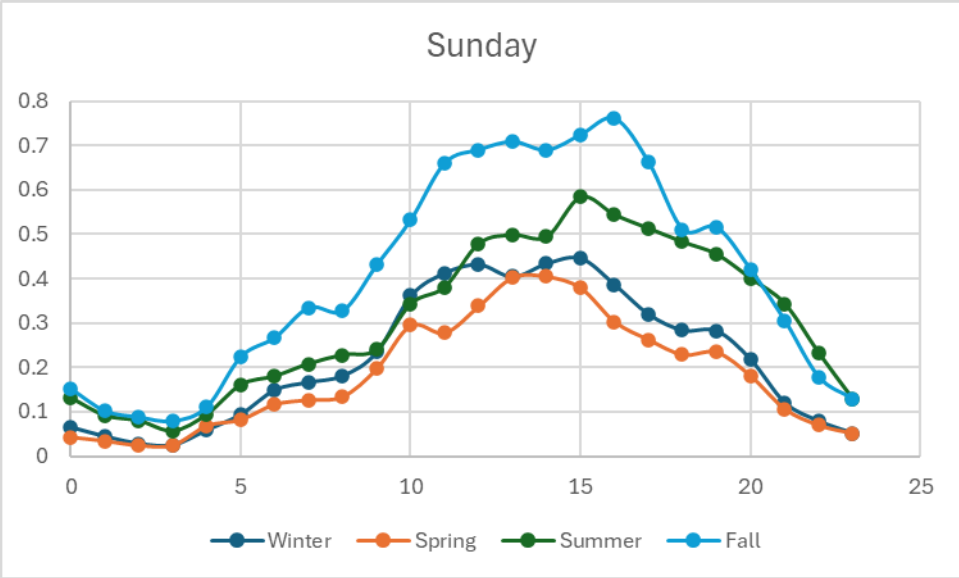

Figure 18 Hourly Usage of Sunday for Each Season

After the presented usages for Monday, Friday, Saturday and Sunday, the approximated usage can be seen in Figures 19 and 20 because after every trip, the device won't be charged which leads to an uncertainty within the charging of the micro-mobility device. Also, another info about the micro-mobility device is the unknown location of the device when the trip finishes. Because of these reasons in this thesis the generated usage profile will be utilized for the simulations.

Based on the generated usage profile, the utilised micro-mobility devices will be scaled and a demand profile for the selected region has been realized. Since the batteries of micro-mobility devices are not changed, when plugged, the charging cycle immediately begins and the utilization during a trip is approximately 1 hours so the demand profile can be realized as Figures 19 and 20 which can be considered as the worst-case scenario.

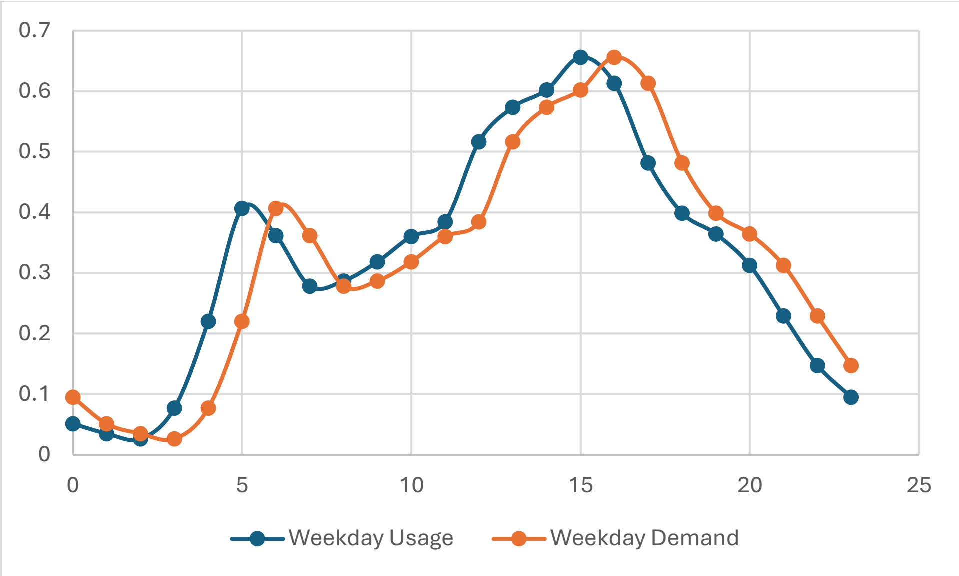

Figure 19 Normalized Average Weekday Usage and Demand

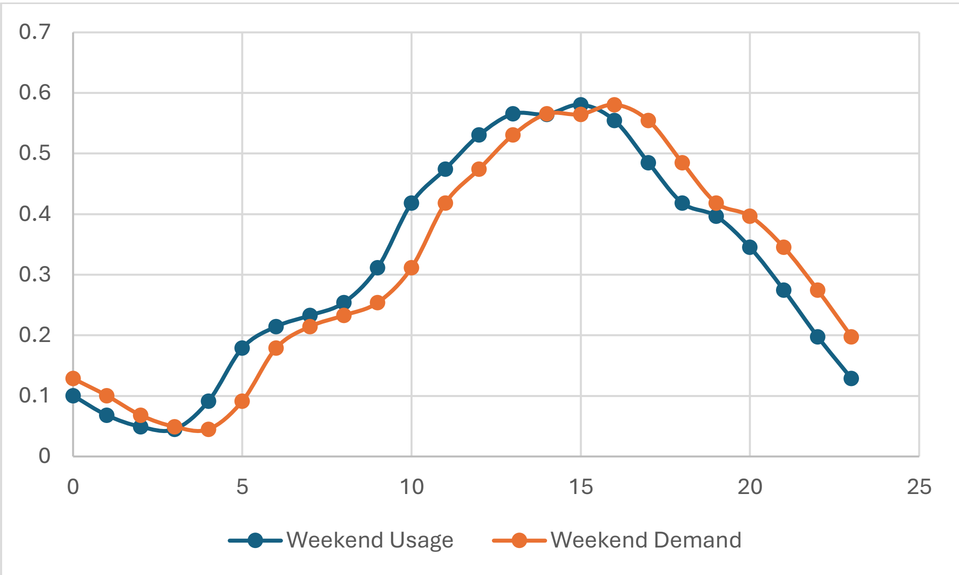

Figure 20 Normalized Average Weekend Usage and Demand

2.3 Load Modelling

The system within the selected region includes residential and non-residential customers such as restaurants, offices, hospitals and schools. As there are multiple buildings with different households and commercial customers, the modelling is achieved via the Artificial Load Profile Generator (ALPG) [52] for residential customers and synPRO [53] for non-residential customers.

2.3.1 Residential Load Modelling

The load profiles are generated based on the household type using Artificial Load Profile Generator (ALPG) from University of Twente [52]. This tool is utilized for Demand Side Management (DSM) purposes with the incorporation of evolving technologies such as EVs and BESSs. The tool takes simulation days, penetration of evolving technologies such as EVs and PVs, power consumption of various devices such as induction stoves, geographical location to gather sunrise and sunset times, predefined household types and the predictability of the people inside the household to allow residents to behave outside the occupancy profile as inputs to the simulation. Some of the predefined households are given in Table 2.

Table 2 Predefined households and corresponding annual consumption

Name	Annual Consumption (kWh)	Persons (Adults)
Single Worker	1610 - 2410 kWh	1 (1)
Dual Worker	2660 - 4060 kWh	2 (2)
Family Dual Worker	3460 - 7060 kWh	3 - 6 (2)
Dual Retired	2660 - 4060 kWh	2 (2)
Single Retired	1610 - 2410 kWh	1 (1)

First of all, when the simulation starts, for each household the accessibility of devices such as dishwashers are determined by probability. The number of children inside the house is chosen by a bounded uniform distribution. The most important part of the artificial load is the occupancy profile which is based on a simple behaviour simulation with 2 outputs; active for being inside the house and inactive which shows that the resident is sleeping and away which leads that the resident is either at work or outside the house. Figure 21 shows the flowchart of the usen tool [52].

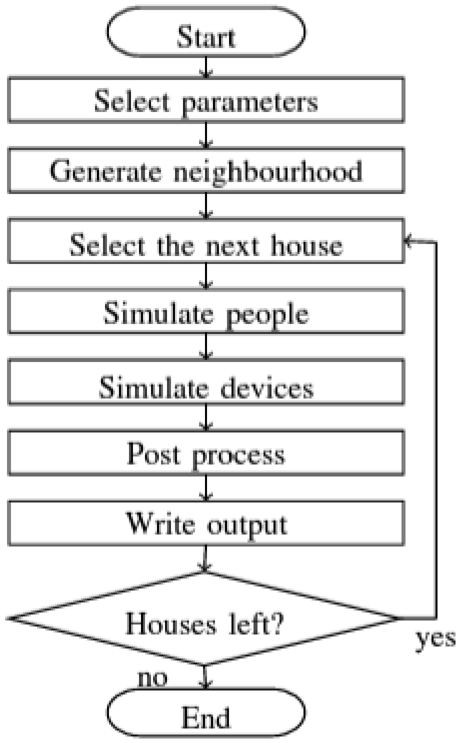

Figure 21 Flow chart of ALPG to generate load profiles

2.3.2 Non-Residential Load Modelling

The non-residential buildings such as school, office, restaurant and hospitals are modelled via the synPRO from Fraunhofer. The synPRO allows the investigation of non-residential consumption using behaviour simulation and thermal information upon the buildings. The flowchart of generating load profiles is presented in Figure 22.

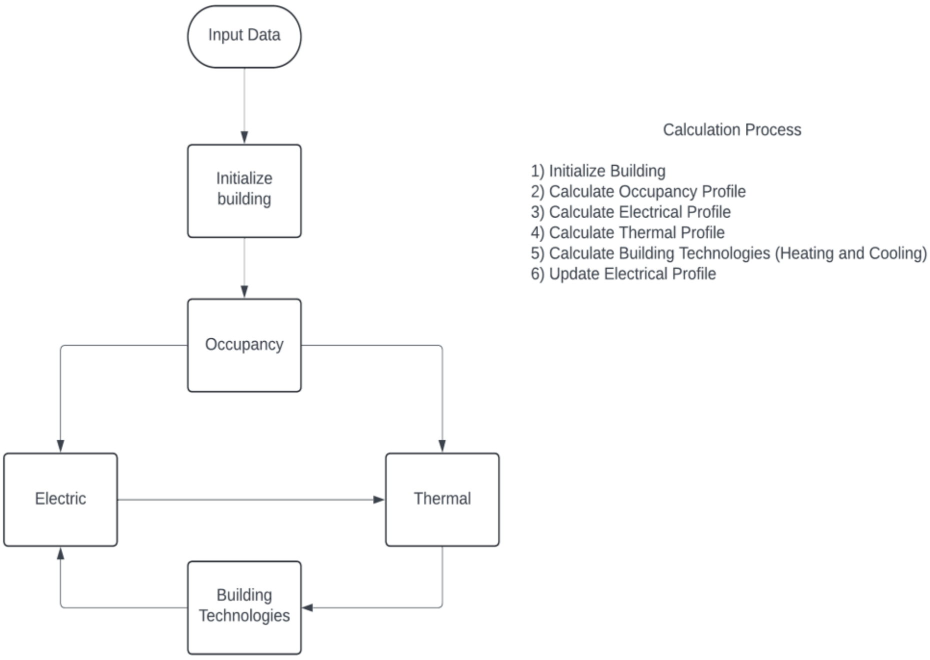

Figure 22 synPRO Flowchart

The occupancy profile for each non-residential customer have been gathered by Time-Use Survey data which elaborates the usage of an equipment based on the time of the day. After the generation of the occupancy profile the next step is the generation of electrical and thermal profile which are based on the built-in equipment in the simulation and the thermal profiles of the buildings which has been verified with the data from the selected region. Based on the thermal profiles, heating and cooling demands are generated and the final electricity consumption is presented.

The utilized building types within synPRO are Restaurant, Hospital, Retail, Office and Hotel. Since the selected region is within a busy city, the inclusion of industry is negligible.

2.4 Test Case

The implementation of micro-mobility is realized with a feasibility analysis and this analysis has been conducted. For the analysis, the available area on the rooftop for the PV panel to be installed is taken as input to create a solar generation profile by linearly multiplying the per m2 generation by the available area. Then the number and type of household inside the apartment is taken as input to calculate the overall load profile of that building and finally month of the year is given as input to the simulation. Based on these parameters and the data collected, the outputs are hourly surplus energy or demanded energy and the number of EVs that has the usage and demand that has been provided before, that can be charged with the surplus energy.

The test scenario considers an average building in selected region. It simulates a building that has 225 m2 rooftop area, The residents are 8 family in which there are more than 1 child, and the parents are working at a full-time job. These assumptions have been verified using the civil registration and nationality from the selected region.

Based on these parameters, it is expected to have an energy surplus during the day since the load is at minimal level as the children are at school and the parents are working and demand after working hours (17:00) since generation is minimal, near zero and household are coming to the apartment.

To continue, after a simulation for 1 year, a maximum of 27.45-kilowatt hour (kWh) surplus energy is expected and with this amount of surplus energy, since the e-scooter has a battery capacity of 720-watt hour a maximum of 38 scooters can be charged simultaneously during the surplus energy time interval. If the usage profile for the EVs that has been provided in Chapter 2, this number decreases down to 16-17 scooters meaning each house can have up to 2 charging spots with this kind of configuration. Figure 23 shows the UI input parameters and Figure 24 shows the output of the simulation.

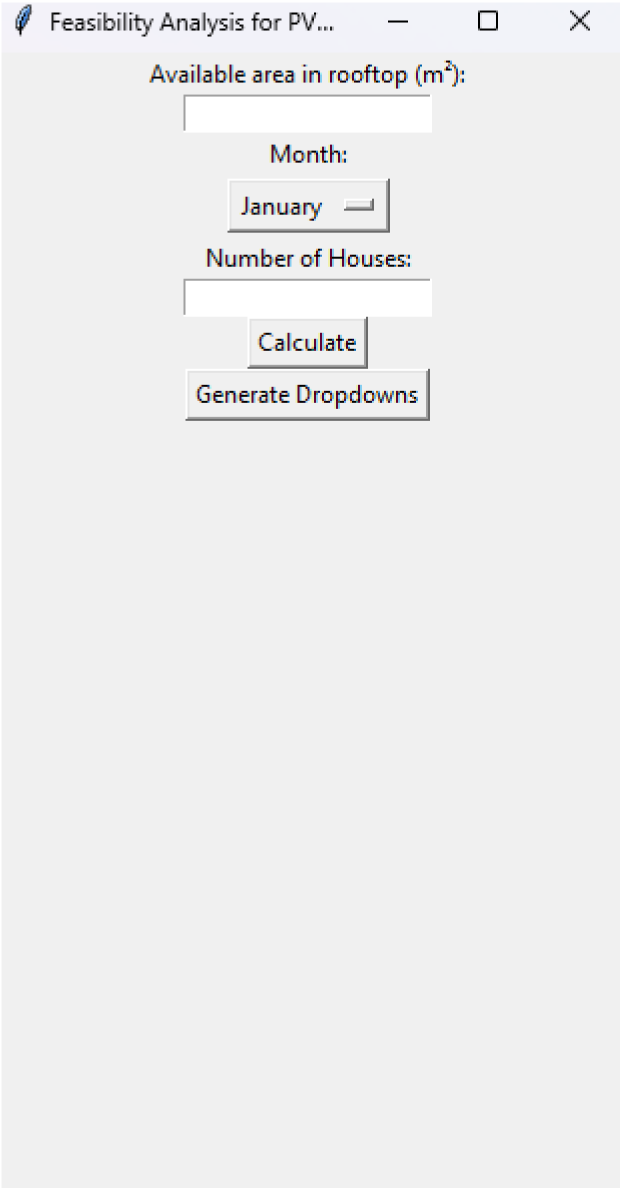

Figure 23 Simulation input parameters

This tool utilizes a very simple business plan it assumes that the charging station is at the parking lot of that building and the scooters have their individual owners but in today's world, as the number of shared micro-mobility companies increase there is no single owner of a device and that device should be chargeable everywhere, it won't turn to the starting place of the trip. Because of this problem, business plans play an important role on the assessment of micro-mobility devices for the concept of NZECs.

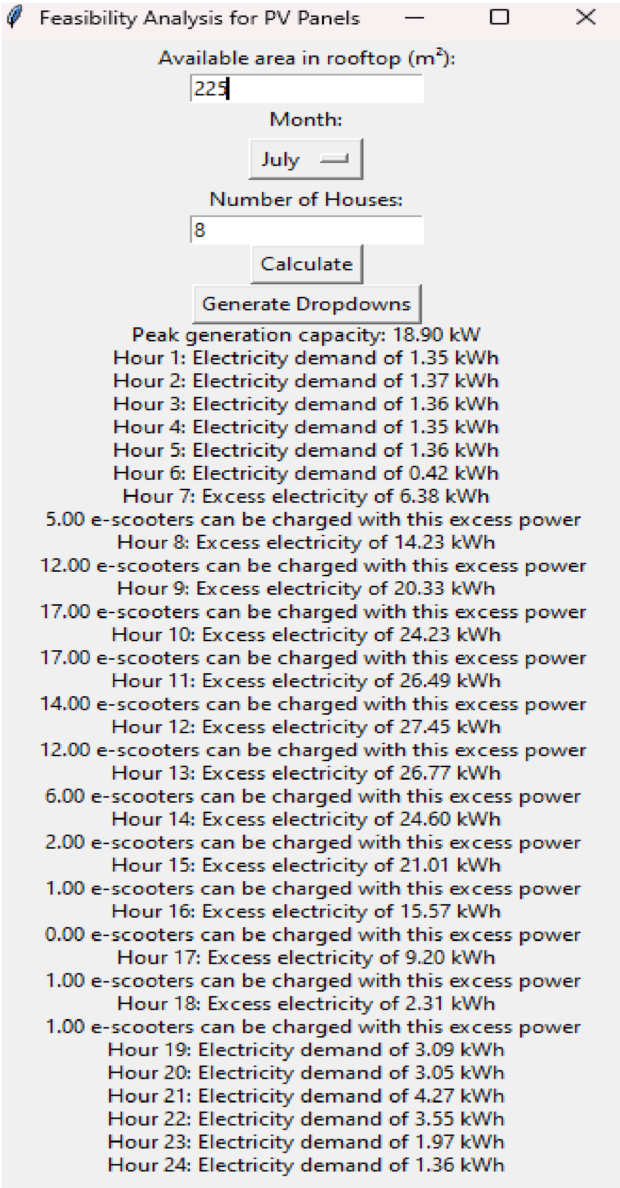

Figure 24 Output of the user interface

The results show us that a building of 8 residential houses can charge up to a total of 17 scooters maximum, which leads to a result of each house can have up to 2 EVs with 720 Wh capacity. This result will be later on used in the rule-based decision-making simulation.

2.5 Business Plans

There are mainly 2 possible business plans for this kind of problem. These are monthly netting and a rule-based controller utilization. Each have their own advantages and disadvantages. In case of monthly netting determination of the location of the PV panels is the priority. These can be schools, apartment blocks or a rented area. The main idea behind this plan is to sell all of the electricity produced to the grid and buy the electricity needed from the grid when needed. At the end of the month the bought and sold electricity needs to be addressed with the distribution company thus there is no need for a third-party company.

In the selected region with the current regulations generated electricity from an unlicensed power plant is bought by the distribution company without a price. This leads to less saving by the stakeholders which leads to a higher return on investment (ROI) value since the monthly netting option is based on the overall sold and bought electricity from the grid and with this kind of plan the stakeholders of the project always pay the distribution cost even if our production is equal to consumption which results in non-zero electricity bill.

According to the current regulatory framework within the selected region, selling the surplus electricity from the demand creates no additional income to the project operator. Because of this, it is essential to choose the BESS size such that the supplied electricity towards the grid decreases and the ROI for such BESS should be within acceptable limits.

With the second option the idea is to design a rule-based controller which decides between charging or discharging the BESS based on time of the day, electricity price and the current generation and load values. Which leads to a more realistic option to achieving zero electricity bill. The time of the day is important because a time of use tariff (TOU) is being considered. The difference between TOU tariff and constant tariff is the different cost of electricity based on the current time instant. The three zones of TOU tariff are.

1) Day time: Between 06:00 AM and 05:00 PM
2) Peak: Between 05:00 PM and 10:00 PM
3) Off Peak: Between 10:00 PM and 06:00 AM

An average normalized load curve and EV Usage in Türkiye is presented in Figure 25.

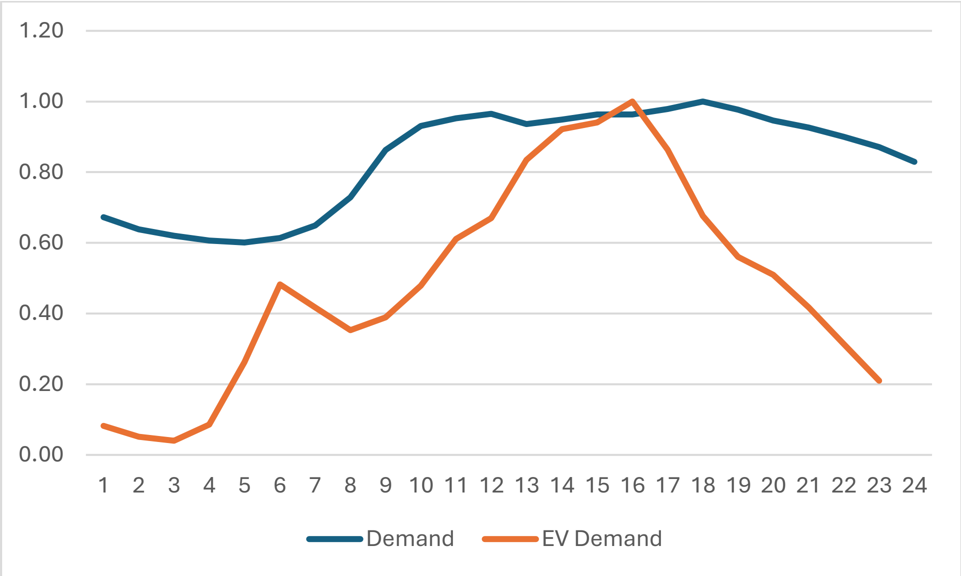

Figure 25 Normalized Load Curve and Shared Micro-Mobility Usage

It is seen that during the day industrial and commercial loads dominates while a higher demand occurs during the peak hours where residential behaviour is dominant. The consumption profile shows us that the consumption profile follows the same trend of increase after 08:00 AM and starts to decrease after 06:00 PM. The peak demand can be seen between 05:00 PM and 10:00 PM where the consumption is at its highest and the EV usage is just after peak demand.

From this graph it can be observed that the electricity prices are published based on the demand values. As the names suggest the electricity is cheapest during night hours since demand is at its lowest values, and the most expensive electricity is during peak hours in which peak demand occurs and the second most expensive tariff is in day-time tariff where industrial loads dominate the load curve creating a near peak demand value which leads to a second most expensive electricity throughout the day.

2.6 Discussion

In this chapter the assessment of micro-mobility devices have been presented. In the simulation, the load values were generated using the ALPG tool from University of Twente [43] which utilizes a behaviour simulation to generate load profiles. The simulation tool uses a very basic business plan in which it assumes that the charging station is at the parking lot of that building and the scooters have their individual owners.

The results shows us that a house can charge up to 2 EVs with 720 Wh capacity if utilization rate of the EV is considered. Furthermore, the business plans namely monthly netting and rule-based controller design approaches have been discussed. The monthly netting option has an advantage of less computational burden, but it cannot be utilized while achieving NZECs because even if the generation is equal to the consumption at each hour, there is a cost named as distribution cost that needs to be paid to the distribution system operator (DSO) in that region. According to the current regulations an unlicensed power plant can sell the excess electricity to the grid without a price. This regulation is realized to make investors think before making such expensive investments.

However, with a rule-based controller this problem can be overcome. It creates a bigger computational burden on the system, but it also enables a path to achieve NZECs.

With this kind of a business plan, it is aimed to have an off the shelf product which enables easy usage without any system specific configuration such as training and validation which are needed for optimization-based controllers. For this business plan, time of use tariff is considered rather than constant rate tariff. The difference comes from the electricity price change during the day. Constant tariff gives a constant electricity price for the whole day however TOU tariff gives a varying electricity price based on the demand values. The considered intervals are daytime, peak and off-peak hours. The daytime tariff is between 06:00 AM and 05:00 PM where industrial loads create the load curve, the peak tariff is between 05:00 PM and 10:00 PM where peak demand occurs with the residential consumers and finally the off-peak tariff is between 10:00 PM and 06:00 AM where there is the minimal consumption occurs.

CHAPTER 3

CONTROL OF NET-ZERO ENERGY BUILDING

In the previous chapter, the system modelling and feasibility studies have been conducted and the result from that chapter shows that a household can have up to 2 EVs within their apartment. In this chapter, two developed controllers, for the purpose of the maximization of benefits inside the system and increasing the BESS lifetime, will be presented and the information about EVs from the previous chapter will be used inside the simulation.

3.1 Rule-Based Control of Net-Zero Energy Building

The developed controller decides when to charge and discharge the battery considering the time of the day, electricity price based on time of use tariff which divides the day into 3-time intervals namely daytime, peak and off peak. Furthermore, the controller takes current generation and demand and the previous decision for the battery as inputs as well.

In literature, it has been demonstrated that frequent charging and discharging of the battery affects the degradation, thus the health of the battery. To mitigate this effect, the developed controller applies the decision that has been taken for 15 minutes to minimize the effects of the cloudiness of the day and to maximize the battery health by reducing the impacts of sudden generation and load changes. Thus, the previous decision of the battery is an important part in this concept because when a decision is made it is essential to keep that decision as long as possible. The decision tree of this concept is given in Figure 26.

The considered rules within the system are:

- Continuity
- Minimum SoC
- Maximum SoC
- Previous battery usage
- Maximum cost of electricity
- Minimum cost of electricity

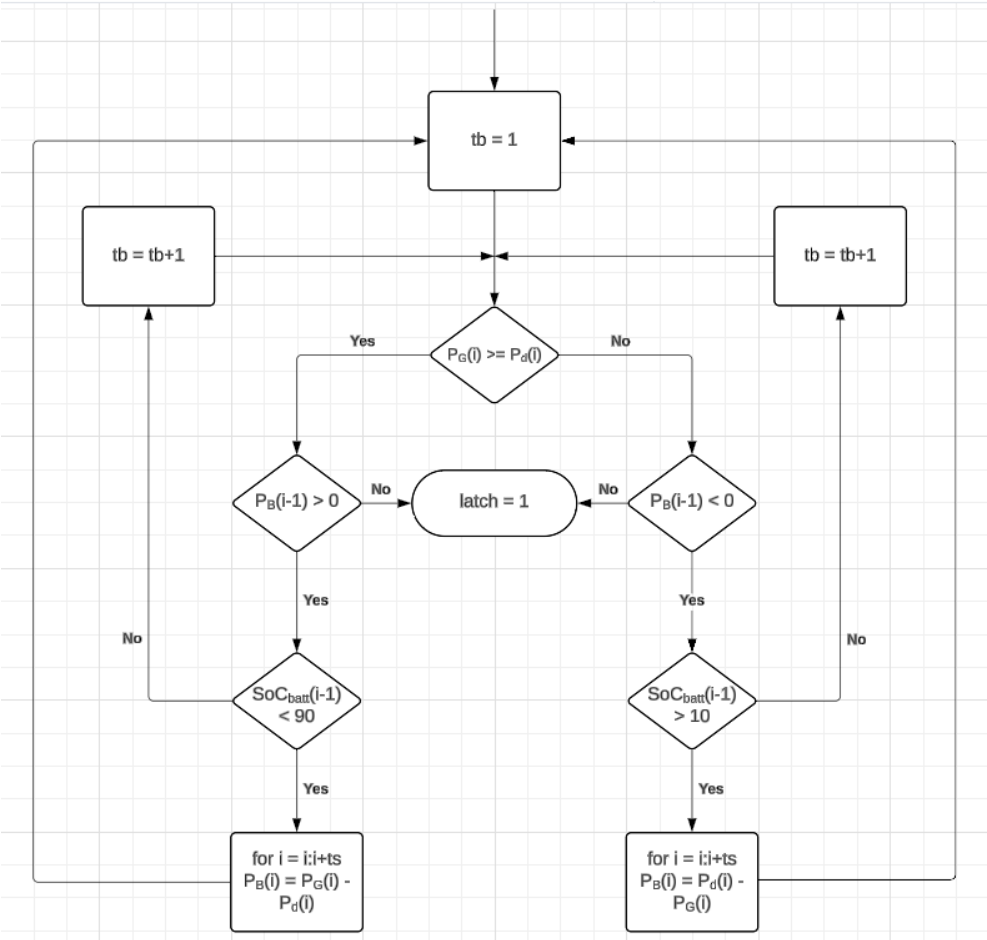

Figure 26 Decision tree for the previous decision

To achieve this kind of configuration, tb, ts, SoC_{batt}, P_B, P_G and P_d parameters are utilized. Tb parameter corresponds to the last time the battery charged or discharged while the ts parameter is the set value of 3 since the controller works on 5-minute resolution and this means a decision is to be applied for 15 minutes. $SoC_{batt}(i)$ shows the current state of charge of the battery, P_B is the battery power and finally P_G and P_d are the generation and demand values respectively.

The controller firstly checks current generation and demand than there are 2 possible outcomes, first one is when generation is higher than the demand and the second outcome is when generation is lower than the demand.

When the first outcome is applicable, the next thing that the controller looks into is the previous decision given in Figure 11. The previous decision taken is determined by the battery power.

If the battery power in the previous time instant is negative it means that the battery has been discharged and if the battery power is positive, it means that it has been charged. If, on the previous decision the battery is charged the controller tends to continue the charging cycle by a charging amount given in equation 1 for ts amount of time.

$$P_B(i) = P_G(i) - P_D(i) \tag{1}$$

If the second outcome is applicable, when generation is less than the demand, the controller checks if in the previous decision the battery was discharged. This decision can only be applicable when peak tariff is achieved since the controller stores all excess electricity for the peak tariff.

If it is peak tariff and in the previous decision the battery was discharged, it is desired to discharge the battery further. The battery power during that time interval is given in equation 2.

$$P_B(i) = P_D(i) - P_G(i) \tag{2}$$

If the previous decision was discharging or the controller than goes into checking the last time the battery was charged or discharged. For this step a parameter called latch has been used. If latch is equal to 1, then it means that the battery was closed, meaning that the battery power P_B has been zero and the upcoming steps given in Figure 27 are taken.

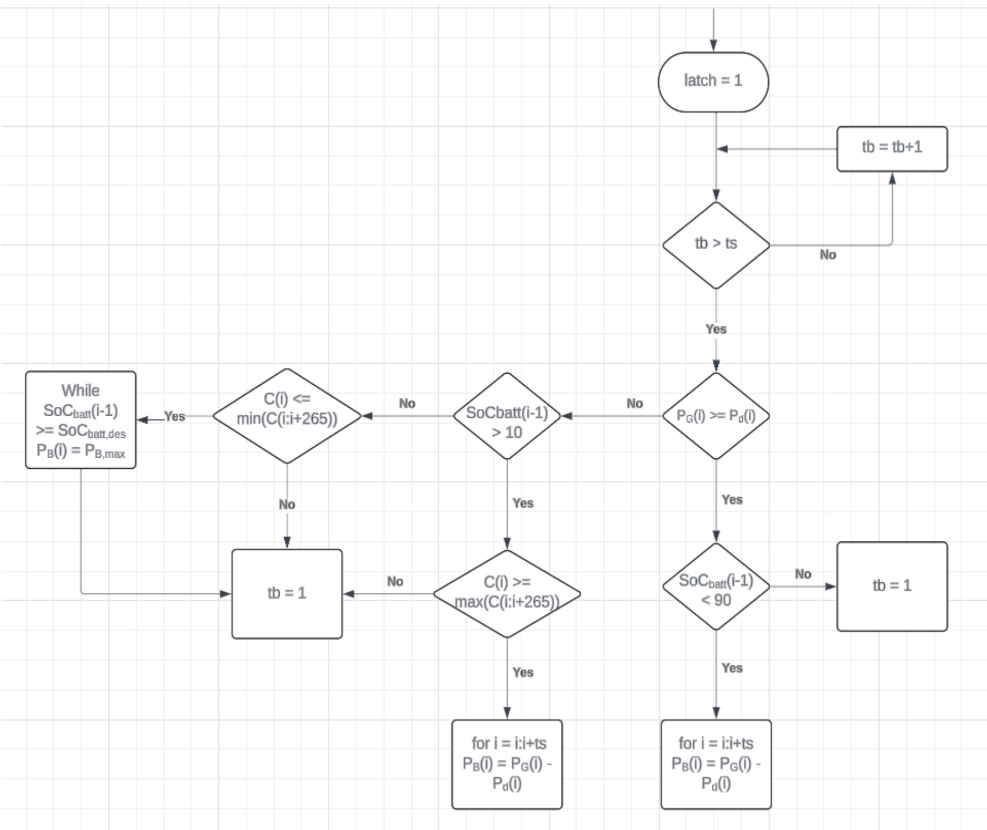

Figure 27 MPC algorithm

If the battery was closed for more than 15 minutes the controller tends to take a different action based on the generation and demand. This part of the decision tree is given in Figure 27.

If the battery has been constant for more than 15 minutes which is determined by checking the tb parameter which shows the last time battery was charged or discharged and if it is greater than the set value ts, based on the generation and demand the controller decides whether to charge or discharge the BESS based on a basic Model Predictive Control (MPC). This MPC corresponds of the future electricity prices based on the time of the day and if the electricity is going to increase on the upcoming hours the controller decides to keep all the stored energy to peak tariff where the electricity is most expensive to reduce the electricity bill and also when electricity is needed for the battery, namely when the SoC of the BESS goes below SoCmin the controller waits for the cheapest electricity to charge the BESS.

This process is being done to increase the resiliency of the system. Since the renewable energy resources depend on weather, it is hard to maintain all customers supplied. To mitigate the intermittent characteristics of the PV panels due to the cloudiness of the day, the BESS is charged during off peak hours where cheapest electricity occurs for the purpose of increasing the reliability of the system.

Apart from this, the BESS is charged if there is surplus electricity throughout the day to minimize the supplied electricity towards the grid and to increase the energy stored in the BESS which than later on will be used in peak tariff with the intention of reducing the electricity tariff.

3.2 Modified Controller Architecture

Another controller architecture that had been developed within the scope of the project has the same basic principles. It charges the BESS during daytime tariff with a constant battery power if surplus electricity is present and discharges it in peak tariff with a constant battery power. However, the difference between the presented architecture and the new architecture is the SoC charging amount during off-peak hours. In the first configuration, a constant SoC rate has been utilized however in reality during summer season the generation is much higher compared to other seasons. The normalized generation comparison between a sunny day in January and June is presented in Figure 28.

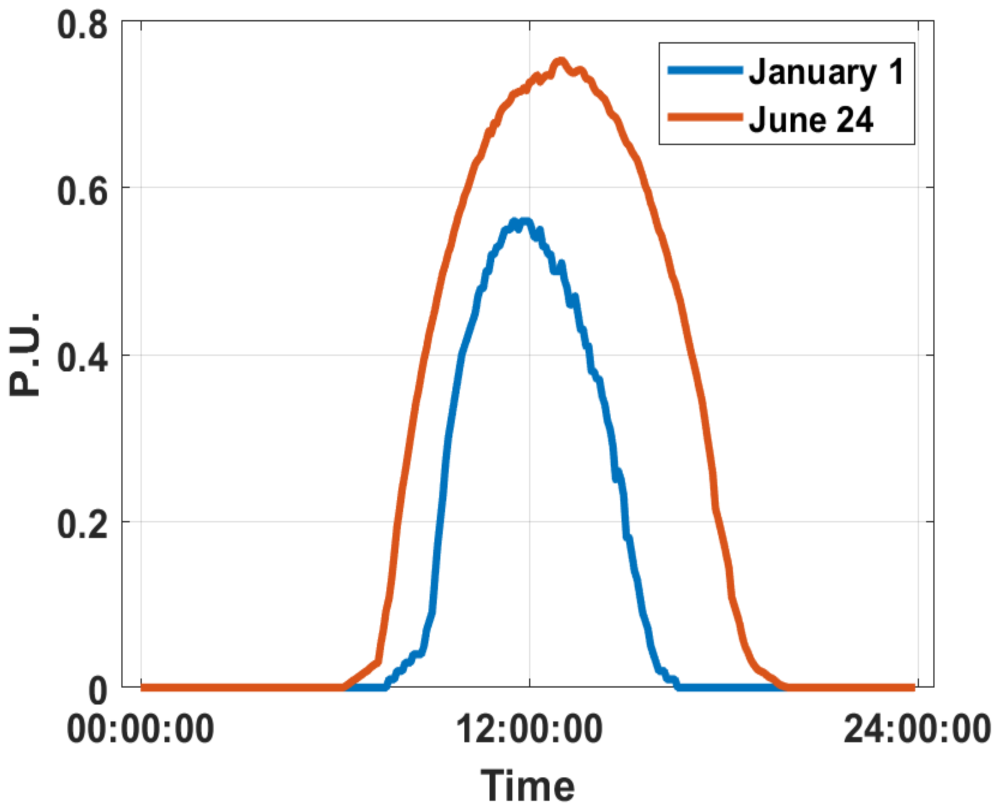

Figure 28 Normalized Generation Comparison of January 1 and June 24

As it can be interpreted from Figure 28, it is vital to allow extra storage within the BESS to store the excess electricity from the demand which is higher than those months where generation is minimal such as non-summer seasons. For this purpose and optimizing the charging and discharging of the BESS to reduce the ROI, consideration of month of the year was added to the simulation. In Türkiye, the duration of sun time increases after March 21st and starts to decrease after 23rd of September. This information is used in the simulation. With this kind of information, the updated decision tree for the MPC part is given in Figure 29.

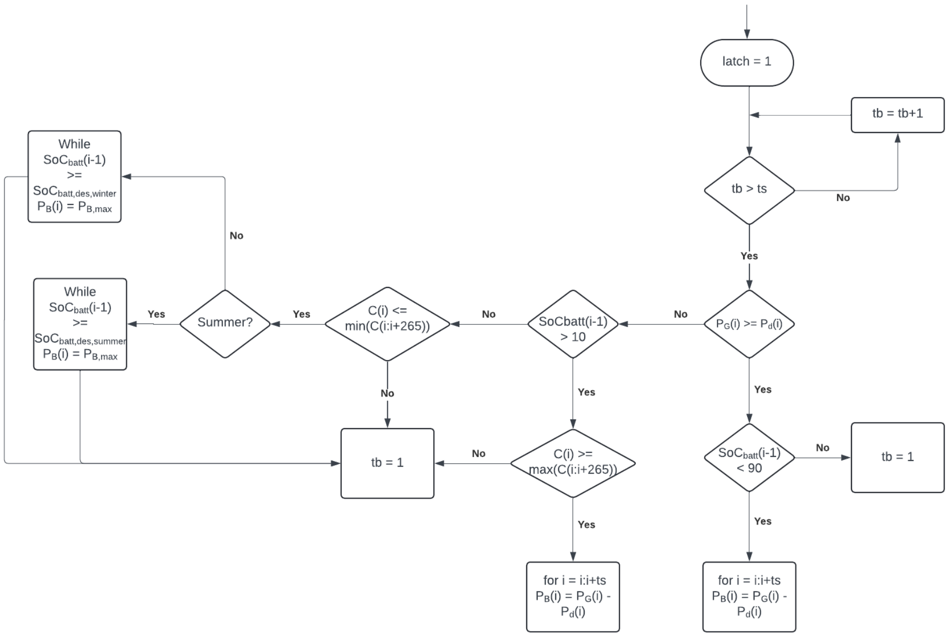

Figure 29 Updated decision tree

The difference between previous decision tree and current decision tree is the summer decision step which ensures that the controller charge the battery according to the user inputs which are $SoC_{batt,des,winter}$ and SoCbatt,des,summer corresponding to the BESS's desired SoC amount during off-peak tariff in winter and summer respectively.

3.3 Discussion

In this chapter two different decision tree for the developed rule-based controller has been presented. The common part for different rule-based controller is the previous decision part of the overall decision tree. The previous decision is important because in literature it has been concluded that rapid BESS power switching and operating mode changing creates significant stress due to the chemical reactions in the battery which ultimately reduces the lifetime of the BESS significantly.

The difference of each controller comes from the MPC part. In the first controller it has been proposed that there should be a constant charging during off-peak hours throughout the whole year. This SoC value can be 0% if the user does not want to charge the BESS or the user can charge the BESS up to 100% but it has been observed that if the SoC value goes higher than 20% the supplied electricity towards the grid increases significantly due to the amount of sunshine received by the PV panels in summer season.

From the first control scheme it has been observed that the SoC cannot go higher than 20% but this creates a limitation on non-summer seasons. During those times since sunshine is lower than those in summer season, the battery cannot be fully charged thus the electricity bill cannot be reduced as much as possible. That is the reason behind the second rule-based controller scheme.

With the second controller, a changing SoC value for summer and non-summer seasons have been implemented based on the time of the year. In Türkiye 21st of March is the equinox day. After that day the sun hours start to increase and the amount of sunlight the PV panels will increase

as well. This increment in the sun time stops in 23rd of September with the second equinox. After that date the daytime starts to decrease.
Based on this information, the controller in the MPC part checks the day and month of the year to see if sunshine is increasing and then it decides to charge the BESS to a lower level to increase the unoccupied capacity of the BESS to reduce the supplied electricity towards the grid.

With this type of control scheme, it is expected to have a lower electricity bill in wintertime where most of the days are cloudy so the BESS can be charged more with a lower electricity price since the charging is made during off-peak hours and then the stored electricity throughout the day is used in the peak tariff where electricity is the most expensive.

CHAPTER 4

RESULTS AND DISCUSSION

In this chapter firstly the considered system architecture will be presented. After that with the simulation parameters the scenario explanations will be made. Furthermore, the results of individual scenarios will be given in graphs and finally they will be evaluated. Simulation and tests are conducted for different scenarios. The considered system is given in Figure 30.

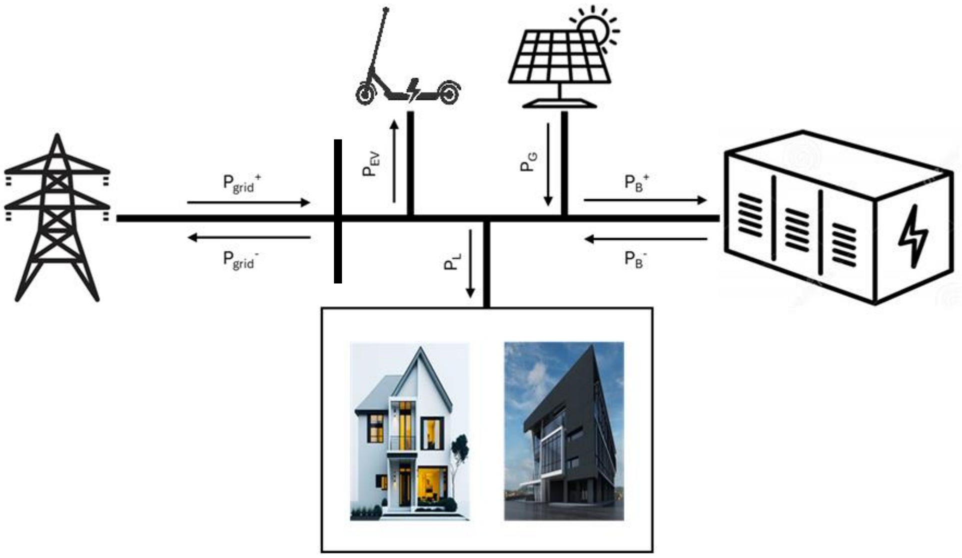

Figure 30 Considered system structure with corresponding power flows

Multiple test scenarios were considered. The control variables during these variables are the BESS capacity, installed PV area, load schedules and the charging amount during off-peak tariff. Fixed parameters during the simulation are given in Table 3. Also, the considered electricity tariff prices are given in Table 4.

Table 3 Simulation parameters

Parameter	Value
Ts	3
P_{max}^{ch} kW	$E_{bat}\times0.6$
P_{max}^{dis} kW	$-E_{bat}\times0.6$
SoC_{max}	90%
SoC_{min}	10%
SoC_{EV}^{int}	0%

Table 4 Electricity price for each quarter of the year

Q1	**Value (TL/kWh)**	**Q2**	**Value (TL/kWh)**	**Q3**	**Value (TL/kWh)**	**Q4**	**Value (TL/kWh)**
Day	4.72	**Day**	4.03	**Day**	4.03	**Day**	4.03
Peak	6.90	**Peak**	5.88	**Peak**	5.89	**Peak**	5.89
Off-Peak	2.98	**Off-Peak**	2.54	**Off-Peak**	2.55	**Off-Peak**	2.55

4.1 Scenario explanations

Scenario 1 is the base scenario. It simulates a residential building which has 287.5 m2 rooftop area for the PV area and there are 32 residents in the building. The load values are generated synthetically by ALPG tool of University of Twente [43].

In the simulation it has been assumed that each house has 2 EVs namely E-Scooters with a battery capacity of 738 Wh which was the result that came from the feasibility analysis in Chapter 2.

Scenario 2 is a building of residential customers. The load values in this simulation have been generated using ALPG from University of Twente [43]. The same EV assumptions are applied. The building has 32 residential customers inside the building with a rooftop area of 243 m2. The difference between scenarios 1 and 2 are the base load amount. In scenario 1 the base load during off-peak hours is around 1.1 kWh and in scenario 2 this value is increased to 1.5.

Scenario 3 simulates a building which includes commercial and residential customers. This building has 28 residential customers and 4 commercial customers. The rooftop area is 225 m2 and the base load is increased to 5.4 kWh during off-peak hours. The same EV principles are still applied.

The final scenario is scenario 4 and it simulates a building with mixed use which has 4 commercial customers and 28 residential customers. The difference between scenario 3 and 4 is the base load. The base load in this scenario is 1.35 kWh. The rooftop area is 226 m2.

All of the building rooftop area is gathered from a point cloud data received from the municipality hall in the pilot area. The load values are also generated based on the resident number, household and usage type in the building.

4.2 Results of Scenario 1

From Figure 31 to 36 the generation, load and the net load of a sunny day during a year is given based on different BESS capacity. Net load is the variable that shows the drawn or supplied electricity to the grid. When net load is above zero the load is supplied from the grid and when it is below zero there is a surplus electricity flow towards the grid. As expected, when the load throughout the day is much less than the generation in a sunny day and when the battery capacity is big enough the surplus electricity amount is not enough to fill the battery but when peak tariff occurs the system reduces the consumption from the grid to reduce the electricity tariff. The spikes on the net load are expected as it is intended to have a constant power for the battery to reduce stress but since generation and load changes, the net load also expected to change.

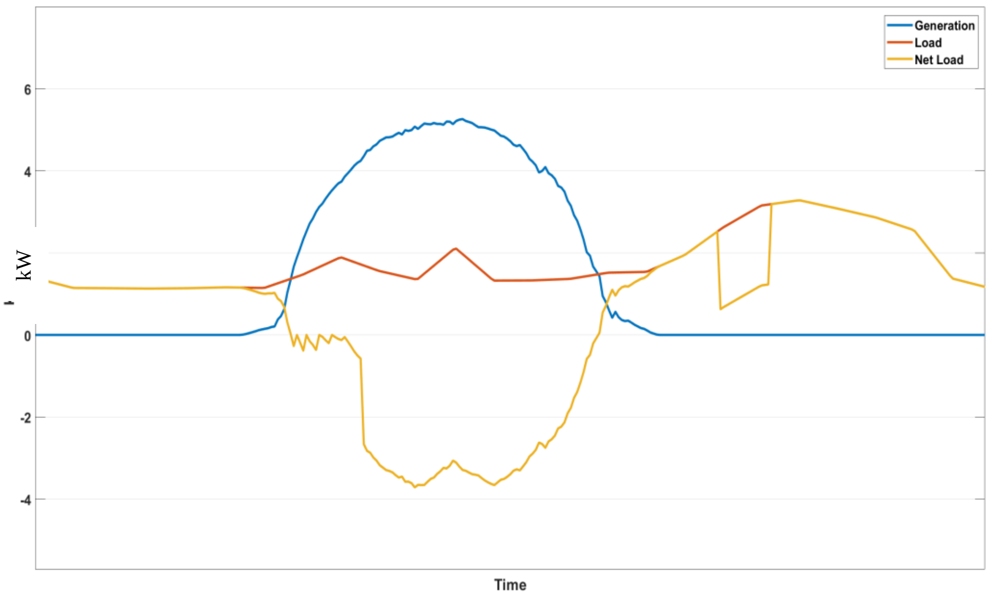

Figure 31 Daily generation, load and net load curve for 3 kWh BESS

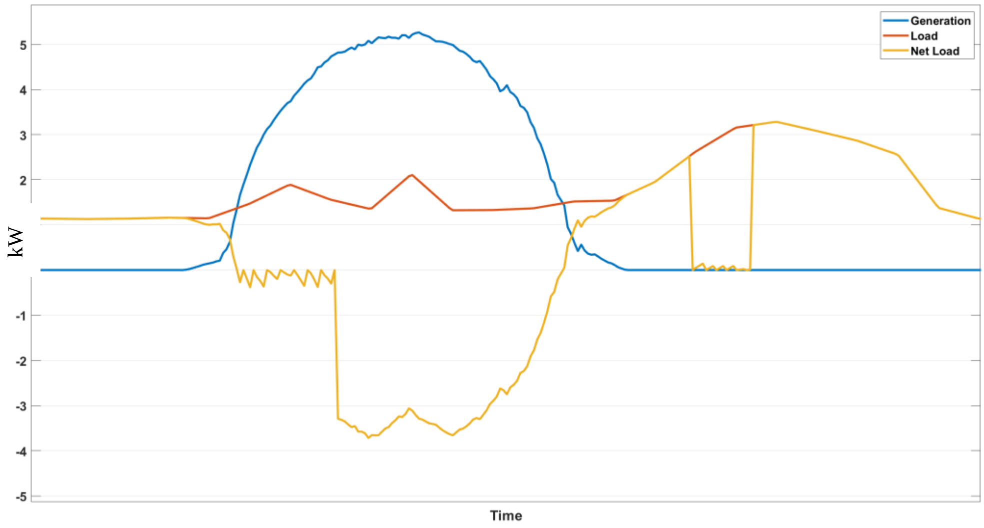

Figure 32 Daily generation, load and net load curve for 5 kWh BESS

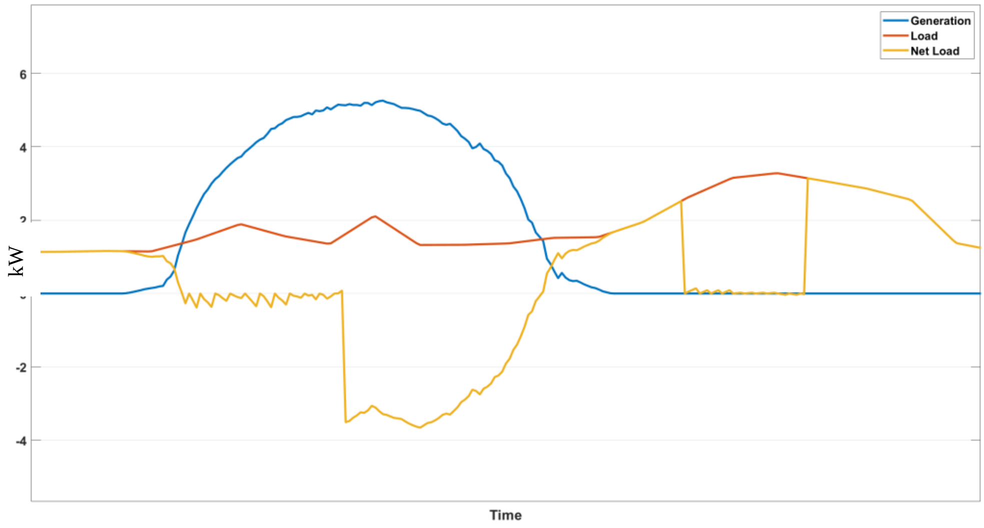

Figure 33 Daily generation, load and net load curve for 10 kWh BESS

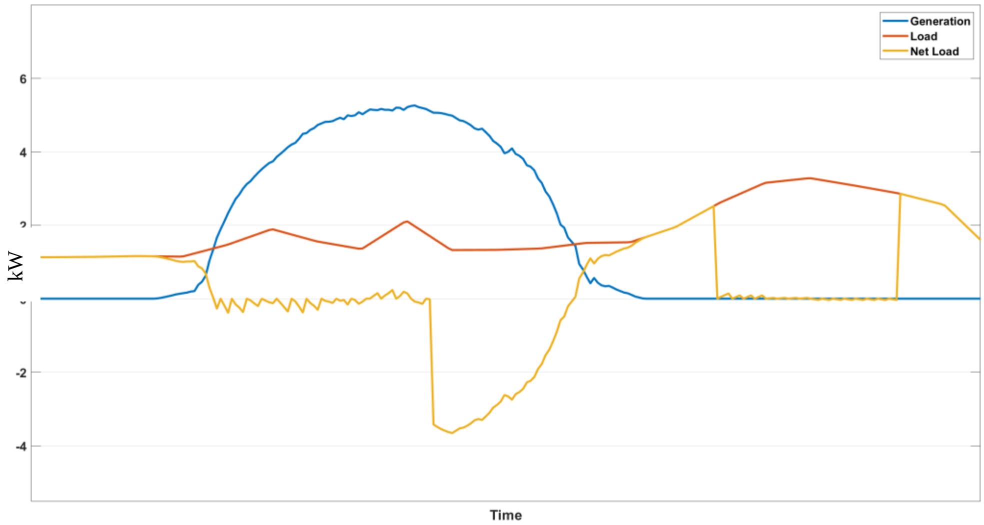

Figure 34 Daily generation, load and net load curve for 15 kWh BESS

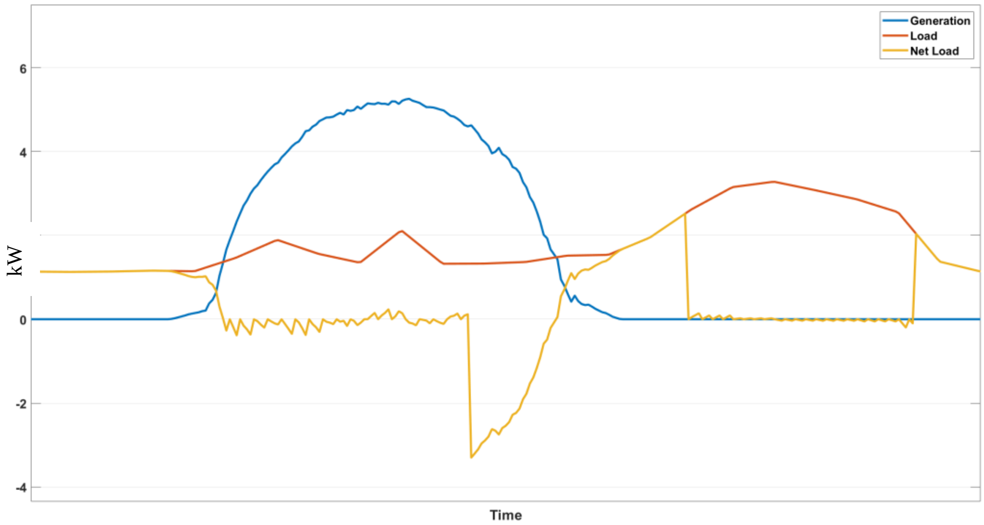

Figure 35 Daily generation, load and net load curve for 20 kWh BESS

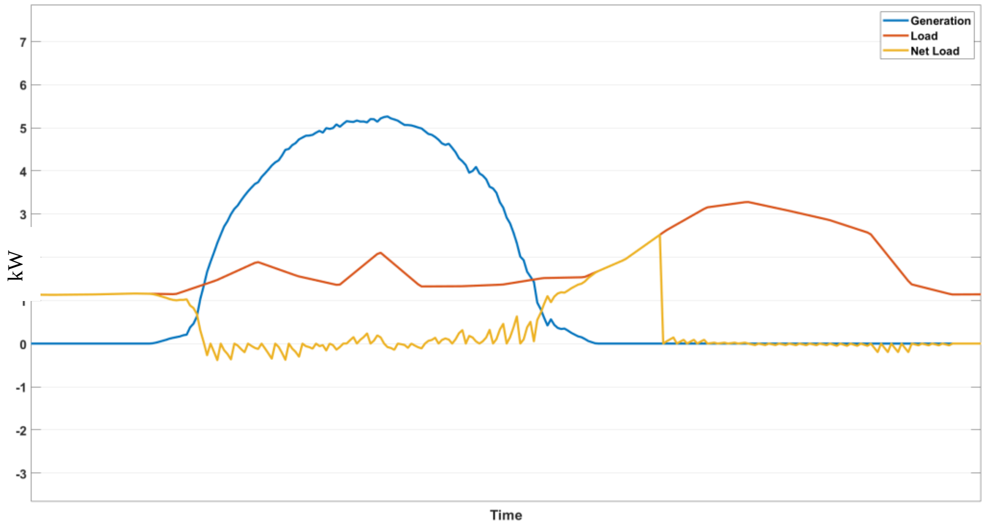

Figure 36 Daily generation, load and net load curve for 30 kWh BESS

The control variable E_{bat} and the corresponding values with the results are presented in Table 5.

Table 5 Results for Scenario 1

BESS Capacity (E_{bat}) kWh	Return On Investment (ROI)	Average Monthly Bill	Current Monthly Bill	Reduction
3.00	1.66	170.05	104.27	38.69%
5.00	2.39		103.04	39.41%
10.00	5.72		102.57	39.68%
15.00	6.23		97.66	42.57%
20.00	7.21		89.43	47.41%
30.00	10.47		81.36	52.16%

4.3 Results of Scenario 2

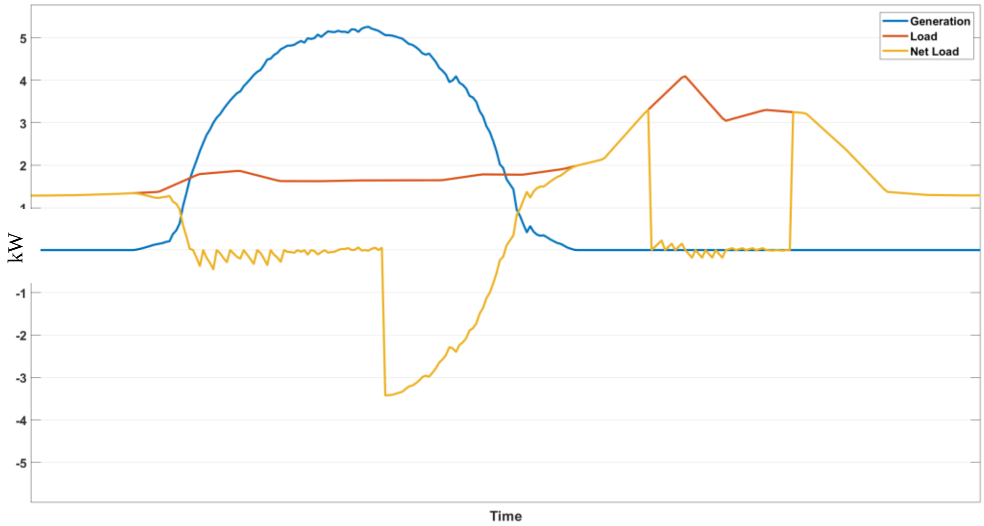

Figure 37 Daily generation, load and net load curve for 15 kWh BESS

The results show that with a 15-kWh battery the peak demand on a sunny day can be supplied with the current configuration as seen In Figure 37. If the capacity is increased, the supplied load towards the grid will decrease significantly but the ROI will increase leading to a more infeasible investment. The results of Scenario 2 are given in Table 6.

Table 6 Results for Scenario 2

BESS Capacity (E_{bat}) kWh	Return On Investment (ROI)	Average Monthly Bill	Current Monthly Bill	Reduction
3.00	1.50	223.96	117.73	47.43%
5.00	2.18		116.40	48.02%
10.00	3.61		115.75	48.31%
15.00	4.89		114.14	49.04%
20.00	5.81		113.46	49.34%
30.00	8.11		95.15	57.51%

4.4 Results of Scenario 3

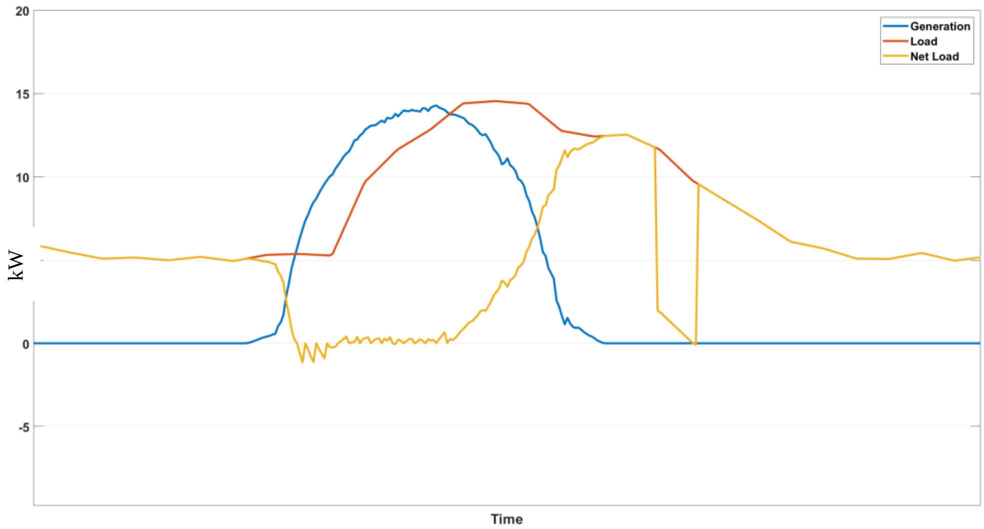

Figure 38 Daily generation, load and net load curve for 15 kWh BESS

With this type of building where load is closer to the generation it is seen that the required BESS capacity to store the surplus is decreased and for that reason the ROI values also decreased however a big disadvantage is that the achievement of net-zero is hard in such case.

From Figure 38 it can be seen that even after a sunny day with a 15 kWh BESS the peak load is barely supplied for an instant and then the BESS SoC went down below 10% which is the hard limit but during the day it can be seen that there is minimal supplied electricity towards the grid which is the advantage for this scenario.

The results of scenario 3 are given in Table 7.

Table 7 Results of Scenario 3

BESS Capacity (E_{bat}) kWh	Return On Investment (ROI)	Average Monthly Bill	Current Monthly Bill	Reduction
3.00	0.83	752.29	550.35	26.84%
5.00	1.08		535.20	28.86%
10.00	1.77		525.24	30.18%
15.00	2.45		518.93	31.02%
20.00	3.07		510.82	32.10%
30.00	4.34		503.92	33.01%

4.5 Results of Scenario 4

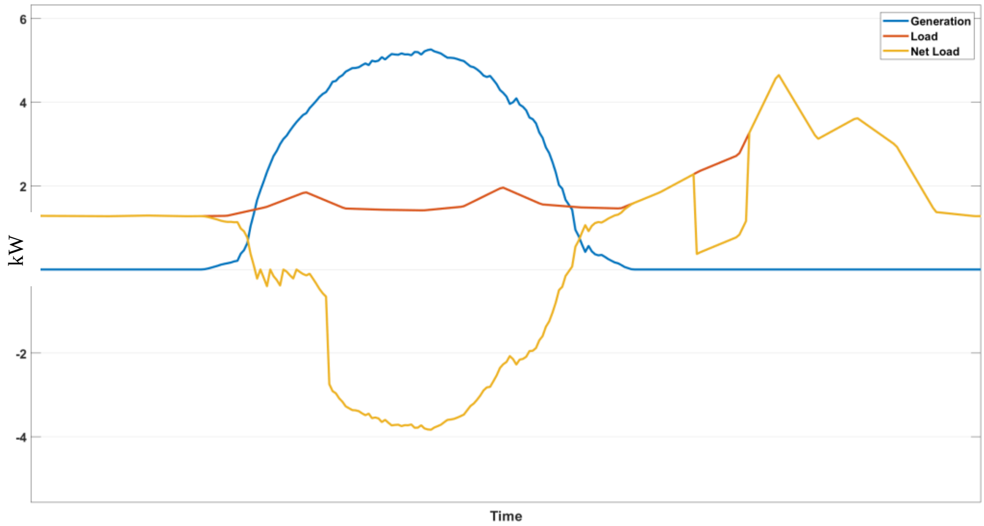

Figure 39 Daily generation, load and net load curve for 3 kWh BESS

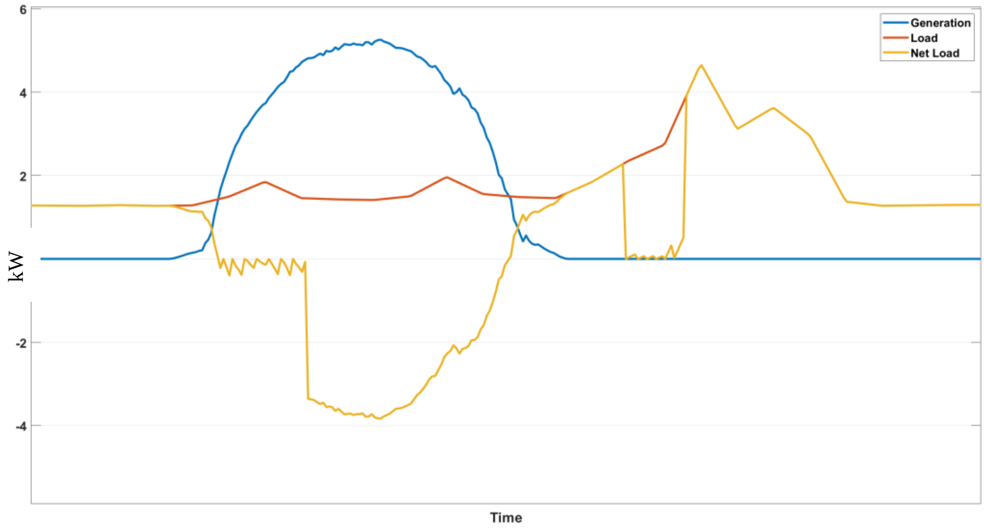

Figure 40 Daily generation, load and net load curve for 5 kWh BESS

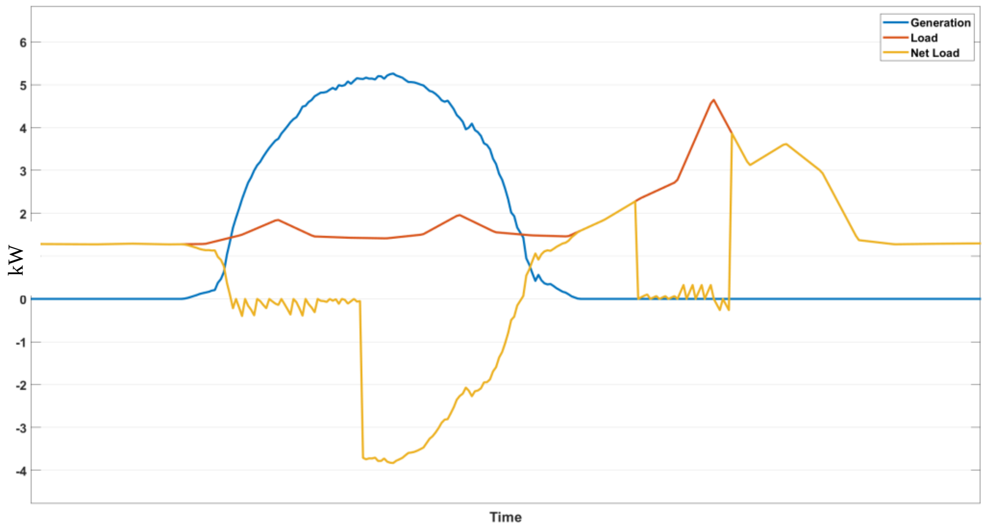

Figure 41 Daily generation, load and net load curve for 10 kWh BESS

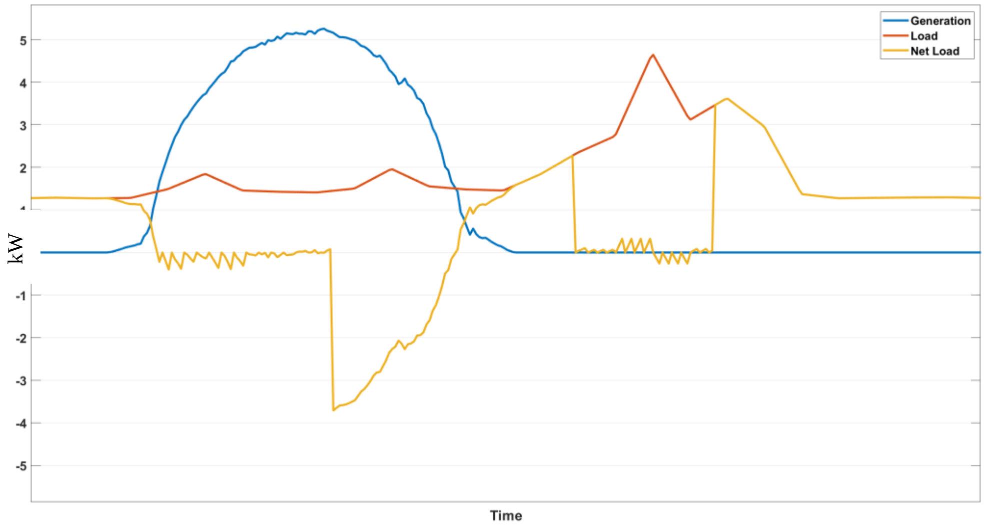

Figure 42 Daily generation, load and net load curve for 15 kWh BESS

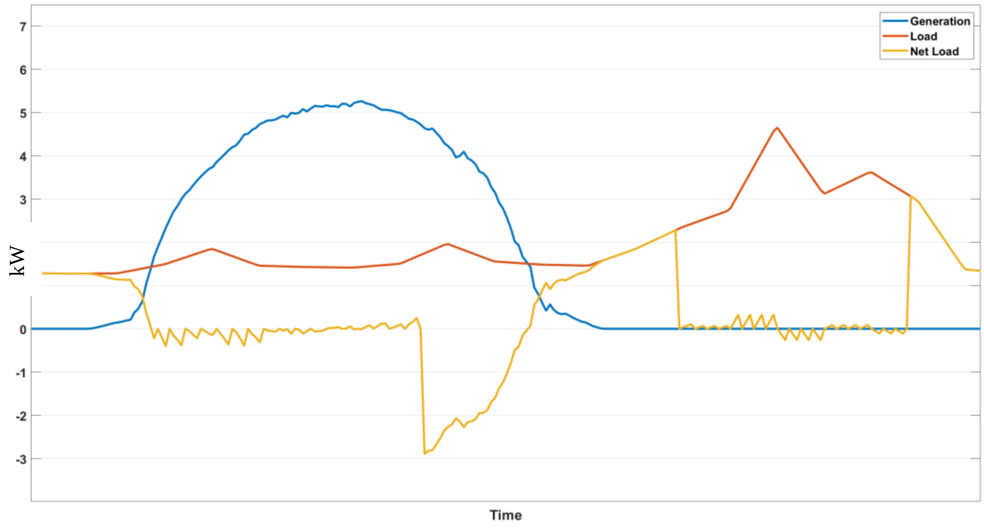

Figure 43 Daily generation, load and net load curve for 20 kWh BESS

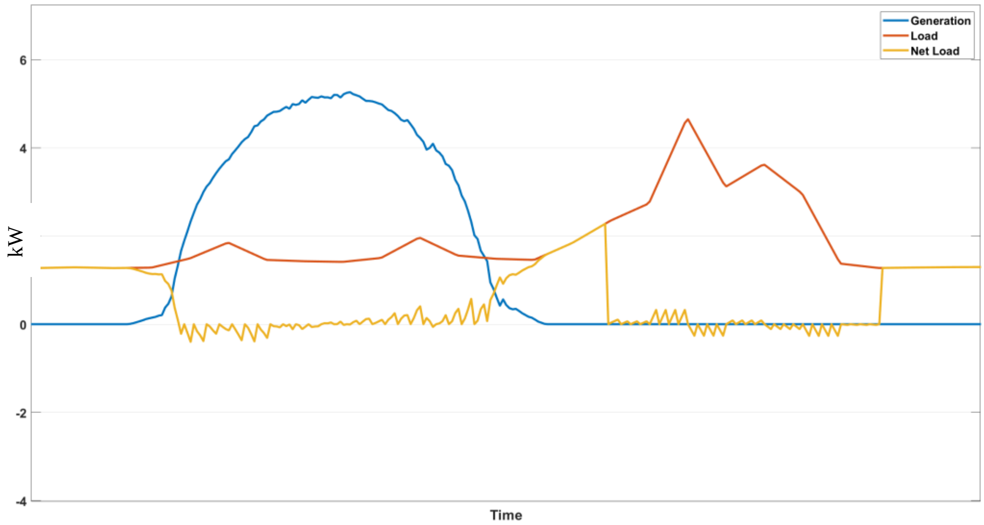

Figure 44 Daily generation, load and net load curve for 30 kWh BESS

The difference between 30 kWh BESS and 3 kWh BESS are imminent such that the net load curve does not spike in negative direction because the SoC of the BESS does not reach up to 90% in 30 kWh case but in 3 kWh BESS, we can see supplied electricity towards the grid which is undesired.

The results of Scenario 4 are given in Table 8.

Table 8 Results of Scenario 4

BESS Capacity (E_{bat}) kWh	Return On Investment (ROI)	Average Monthly Bill	Current Monthly Bill	Reduction
3.00	1.56	219.58	112.77	48.64%
5.00	2.03		110.15	49.83%
10.00	3.24		105.29	52.05%
15.00	5.44		102.42	53.36%
20.00	6.72		99.33	54.76%
30.00	7.79		95.21	56.64%

4.6 Modified Controller Results

After these scenarios for a different perspective, another case type was implemented. In this case, since the PVs can be intermittent due to seasonality and weather conditions, to increase the resiliency of the system in case of a cloudy day, in order for the system reduce the electricity consumption during off-peak hours when the electricity is the cheapest the BESS is charged such that it increases the resiliency and reduces the supplied electricity towards the grid. For this reason, to compare the results same buildings in scenarios 1 to 4 are used.

The results show that if this kind of configuration is used for small BESS size the effect of charging during off-peak hours is negligible however in case of a large BESS size the difference between no charging and charging cases of each scenario gets bigger.

This conclusion is consistent with the Net load graph in all of the scenarios for 3 kWh BESS capacity. As it can be seen when peak tariff is achieved the battery starts to discharge but the net load does not come to zero since the capacity of the BESS is not enough, as the size gets bigger the ROI value increases but the electricity bill decreases. This result shows us that not every building should have a small BESS since it won’t affect the bill so much. To reduce the bill further higher BESS capacities are needed but when such case occurs, most of the time the ROI increases as the reduction of the bill cannot overcome the increment in the overall cost which includes cost of BESS and installation cost of the PVs.

The controller during these intervals charges the BESS to a rather lower level to those outside this interval. This scenario ensures, during non-summer seasons when cloudiness can occur throughout the day which would minimize the PV generation, the bill still reduces and during summer it guarantees the minimization of the supplied electricity to the grid as it reduces the required SoC value for the BESS to achieve during off-peak hours.

This type of configuration can be used in larger scales of batteries since in the previous scenario it has been demonstrated that in small scale BESS charging of the BESS does not create a significant impact on the electricity bill and also it creates additional cycles on the BESS which ultimately reduces it lifetime which is a major problem while utilizing a BESS. The major finding during these simulations is that when the SoC of the BESS is charged higher than 20% the amount of electricity supplied towards the grid becomes significantly large. This kind of an impact is not wanted while achieving net zero because it means that the system cannot handle the generation from the PV while it should be able to.

Also in such cases, according to regulations, the supplied electricity towards the grid is not entitled to a penalty however the distribution company buys it with zero cost. Meaning that there is no income to the shareholders of the system. This regulation is meant to make investments thoughtful and carefully reviewed because it means to achieve net zero.

From these simulations it can be observed that having no night charge is usable for smaller BESS sizes however if the size gets higher a desired SoC value should be implemented to the controller to increase the resiliency of the system. This is because when the BESS capacity is low if the BESS is charged during off-peak hours there is little to no available capacity for the surplus electricity in daytime but as size increases the available capacity of the BESS increases as well.

To mitigate this issue, the developed SoC charging of the BESS in summer and other seasons have been implemented. Figures 45 to 48 corresponds to the generation, load and net load of each scenario for their corresponding BESS capacities after the new implementation. The BESS capacities are 15, 15, 15 and 20 kWh for Scenarios 1, 2, 3 and 4 respectively.

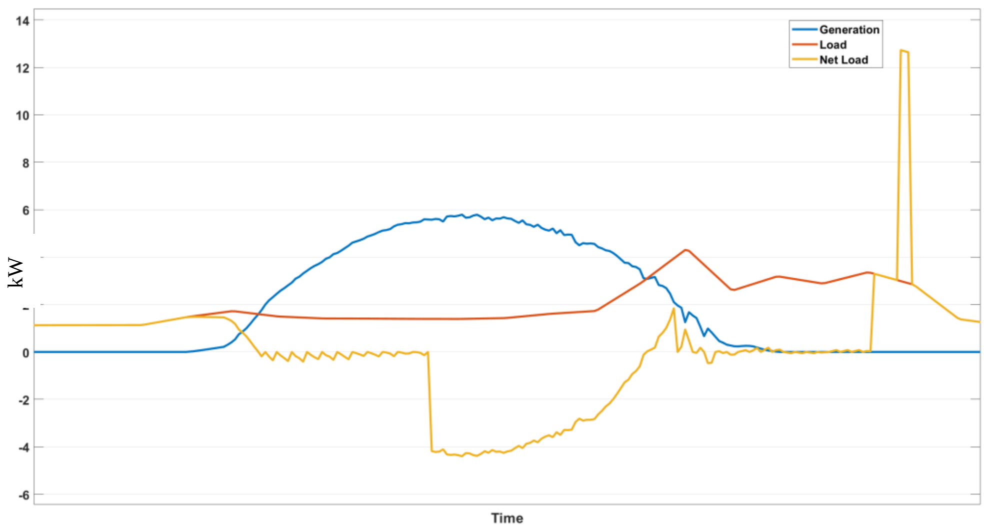

Figure 45 New configuration 15 kWh for Scenario 1

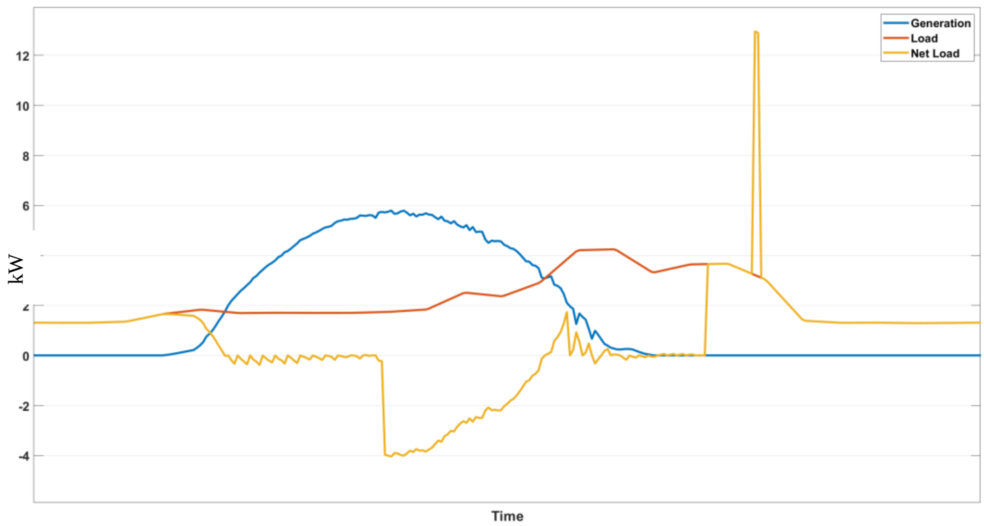

Figure 46 New configuration 15 kWh for Scenario 2

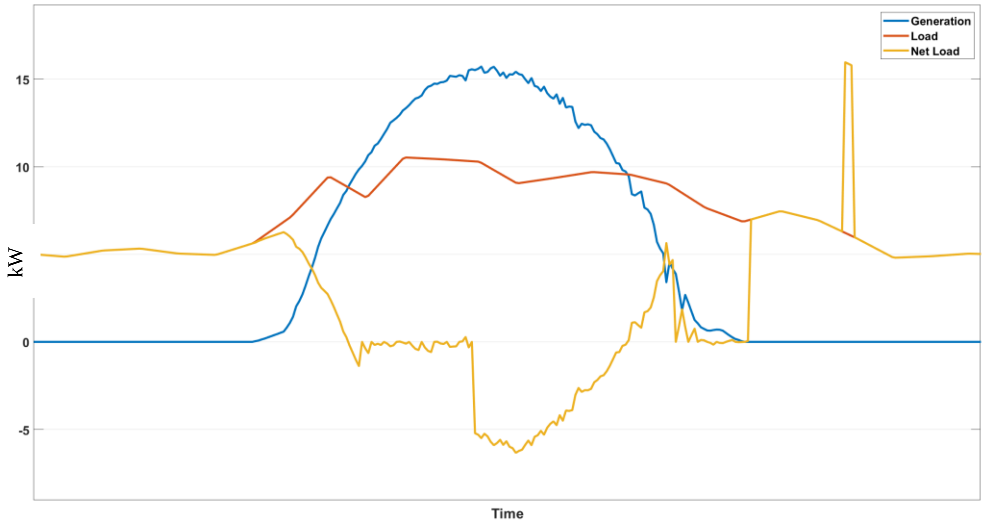

Figure 47 New configuration 15 kWh for Scenario 3

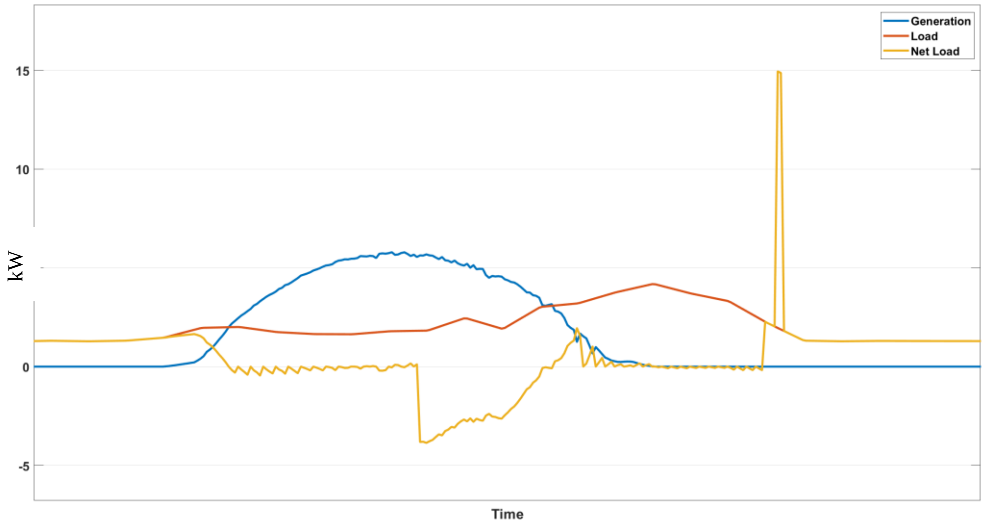

Figure 48 New configuration 20 kWh for Scenario 4

The corresponding SoC and BESS power graphs of those days are presented in Figure 49 to Figure 52. A result that can be interpreted from these graphs is that when night charging is at a certain level, in this case it is 20% the resiliency of the system increases and since the day is not cloudy the BESS is fully charged in all sizes of the BESS.

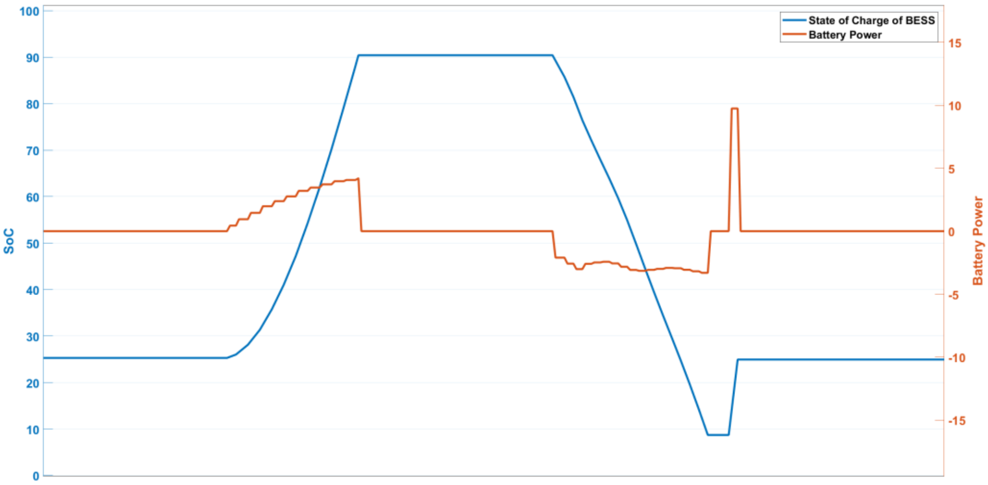

Figure 49 New configuration 15 kWh SoC and Pb for Scenario 1

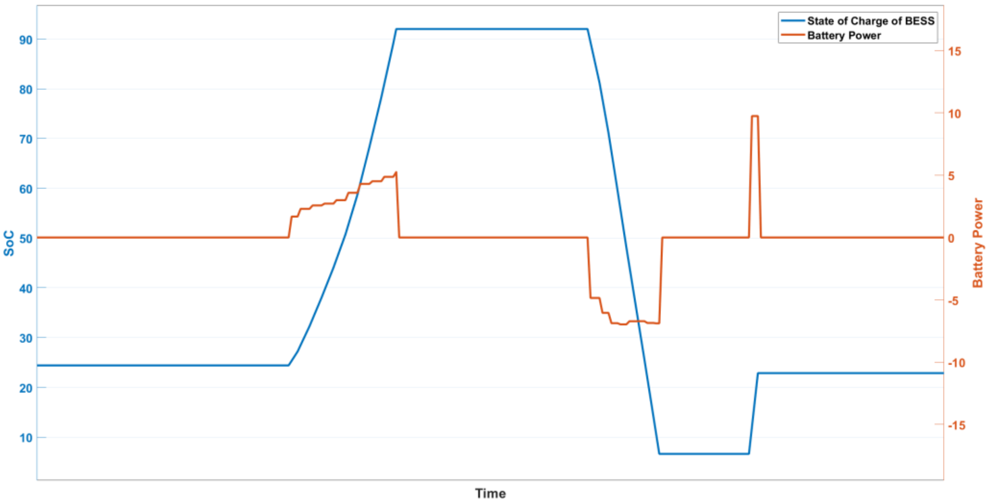

Figure 50 New configuration 15 kWh SoC and Pb for Scenario 2

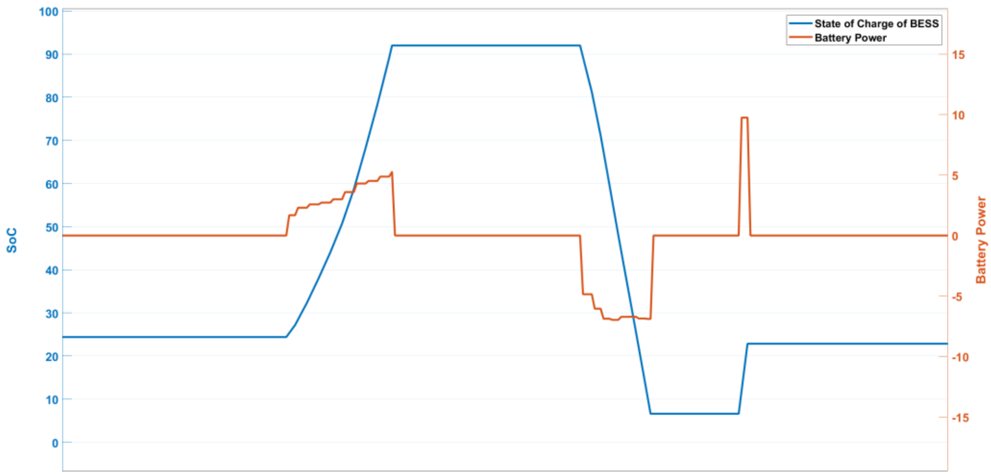

Figure 51 New configuration 15 kWh SoC and Pb for Scenario 3

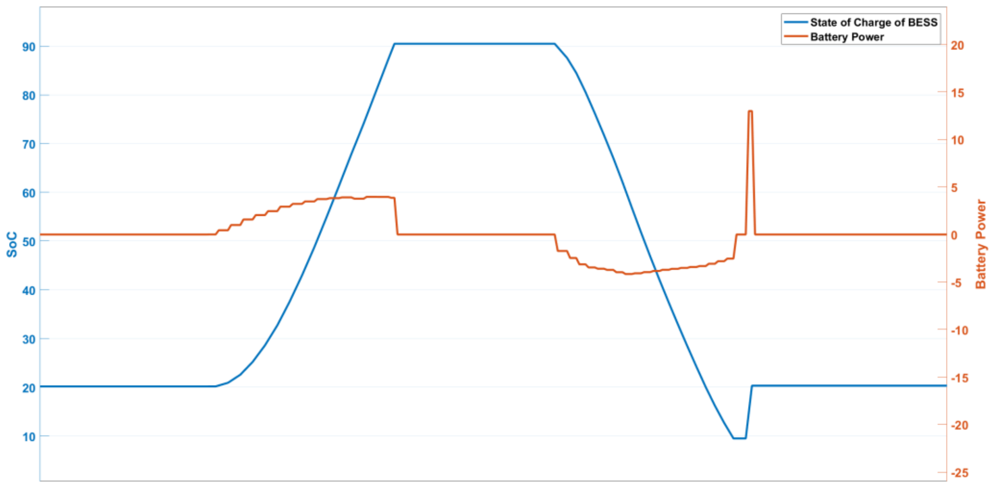

Figure 52 New configuration 20 kWh SoC and Pb for Scenario 4

4.7 Discussion

In the discussion of the first controller results, Scenario 1 suggests that for this type of residential building, a Battery Energy Storage System (BESS) of 15 kWh or higher, depending on the customer's return on investment (ROI) preference, should be utilized. This configuration leads to the lowest electricity bill while minimizing the amount of electricity supplied to the grid. The analysis shows that as the BESS size increases from 3 kWh to 30 kWh, the ROI extends from 1.6 years to 10.5 years. In this scenario, each house is equipped with 2 electric vehicles (EVs), and the building has a photovoltaic (PV) area of 8 m^2, in line with regulations requiring the peak generation capacity to match the peak demand. The results indicate that when the load exceeds generation, a larger BESS is necessary to minimize electricity exports. However, while a 30 kWh BESS minimizes these exports, the ROI becomes unfavourable, stretching up to 10 years. Therefore, a 15 kWh BESS is considered optimal, balancing cost-effectiveness and performance.

In Scenario 2, the building's overall and peak demand are higher than in Scenario 1, making it possible to use a larger BESS with a similar ROI. A 10 kWh BESS results in an ROI of 3 years and 11 months, while a 15 kWh BESS increases the ROI to 5 years and 3 months. Despite this increase in ROI, the electricity bill is significantly reduced, from 119 TL to 103 TL, offering an approximate annual savings of $118 for the entire building. In contrast, in Scenario 1, a 5-year ROI could only be achieved with a 10 kWh BESS.

Scenario 3 demonstrates that when the load is close to matching the generation, the BESS rarely charges beyond 90% capacity. However, this also leads to a significantly improved ROI, since reducing consumption during peak hours generates considerable savings. In this scenario, a 15 kWh BESS reduces the electricity bill from 752 TL to 519 TL, resulting in an ROI of 2 years and 6 months. Another viable option would be a 20 kWh BESS, which delivers a reasonable ROI of 3 years.

In Scenario 4, the results indicate that for the given load and generation values, a 20 kWh BESS is the best option. It can meet the building's peak daily demand while storing surplus energy throughout the day. For a single customer, the electricity bill decreases from 220 TL to 100 TL with the use of a 20 kWh BESS.

The discussion of the second controller reveals more adaptive strategies for managing the BESS. In Scenario 1, a notable spike in BESS charging occurs toward the end of the day during off-peak hours. This behaviour changes during the non-summer months, where charging is limited to 50%, an adjustable value. For this type of residential building, setting the State of Charge (SoC) to 50% during the non-summer season is optimal, as it maintains reasonable capacity while aligning with existing literature, which suggests that a 50% SoC is ideal for maintaining the battery's State of Health (SoH). With this configuration, the average monthly electricity bill drops from 199.6 TL to 77.7 TL, with a reduced ROI of 4.45 years.

In Scenario 2, without off-peak charging, a 15 kWh BESS initially provides an ROI of 4.89 years. However, with adaptive charging based on the season, the ROI improves to 4.32 years, representing an 11.6% reduction.

In Scenario 3, utilizing a 15 kWh BESS results in an ROI of 2.3 years for both the BESS and PV investment, and the average monthly electricity bill drops from 752.3 TL to 483 TL.

Finally, in Scenario 4, using a 20 kWh BESS with the new controller architecture reduces the electricity bill from 219.6 TL to 92.5 TL. This significant reduction is particularly pronounced during the non-summer seasons, especially in winter, where the optimized charging strategies create a substantial difference in costs.

The corresponding results for each scenario are given in Table 9

Table 9 Difference between different controller architecture

E_{bat} (kWh) Scenario 1	Return On Investment (ROI)	Average Monthly Bill	Current Monthly Bill
15.00	6.23	170.05	97.66
15.00	4.45		77.72
E_{bat} (kWh) Scenario 2	Return On Investment (ROI)	Average Monthly Bill	Current Monthly Bill
15.00	4.89	223.96	119.14
15.00	4.32		105.29
E_{bat} (kWh) Scenario 3	Return On Investment (ROI)	Average Monthly Bill	Current Monthly Bill
15.00	2.45	752.29	518.93
15.00	2.28		483.03
E_{bat} (kWh) Scenario 4	Return On Investment (ROI)	Average Monthly Bill	Current Monthly Bill
20.00	6.72	219.58	99.33
20.00	5.99		92.53

With the addition of seasonality, it is expected to have a decrease in ROI until an optimum BESS capacity is achieved but this outcome occurs in limited number of buildings. An example graph of ROI vs BESS size is given in Figure 53. This building has 28 residential customers, 1 restaurant and 3 office demand. From the graph, it can be interpreted that a BESS of 30 kWh can be utilized for this type of building.

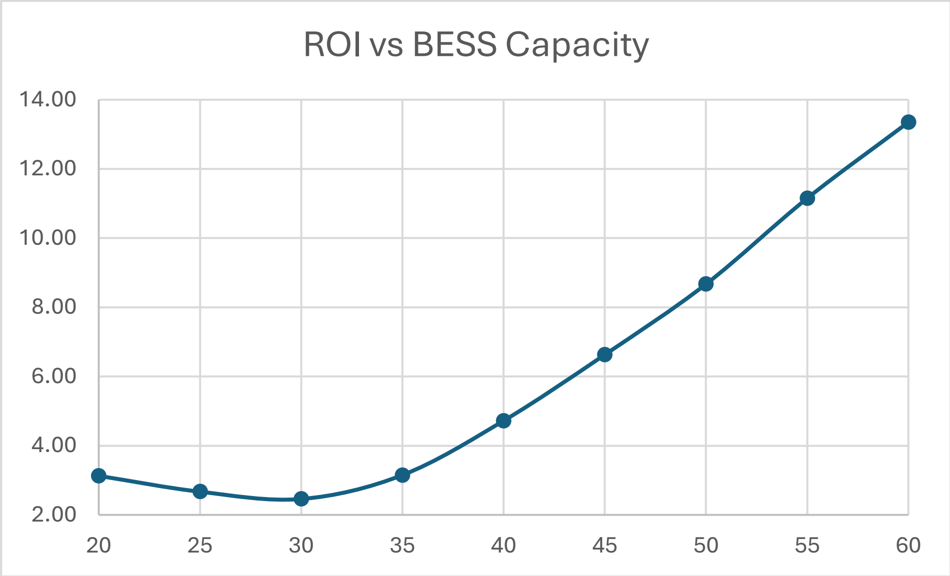

Figure 53 Mixed Usage Building ROI vs BESS Capacity

4.8 Summary and conclusion

In this chapter the impact of implementing EVs, PVs and BESS upon the ROI have been analysed. The physical components such as available m^2 for the rooftop, the households and their usage type for the test buildings have been assembled from a point cloud data for Kadıköy in İstanbul. The load values for those buildings were realistically generated from load profile generator tools such as ALPG from University of Twente [43] and synPRO from Fraunhofer [44].

For the first controller scheme, a constant SoC for summer and non-summer seasons have been implemented which reduces the overall resilience of the system because if the SoC value increased above 20% in off-peak tariff, after 21st of March, the supplied electricity to the grid increases significantly but if it is reduced, during non-summer seasons when the day is mostly cloudy, rainy or snowy, since the PV panels could not optimally generate electricity, the BESS cannot fully supply the peak demand of the building. In such configuration, the ROI of each scenario is still in acceptable limits between 2 years and 7 years. As the capacity of the BESS increases in the same building, the ROI also increases, that is why there should be a decision by the shareholders about the BESS capacity.

For Scenario 1, if a 3 kWh BESS is to be implemented, the expected ROI would be 1.6 years, but the electricity bill would only reduce 38% however if 15 kWh BESS is to be implemented, this reduction would increase to 40% with an ROI of 2 and five months. This reduction can go up to 52% with a 30 kWh BESS but the ROI would increase up to 10 years and 6 months. For this case 15 kWh BESS can be considered as an optimum capacity since it has an ROI of 5 years and 6 months also it ensures enough reduction on the bill as well as enough storage area for the building.

For the second scenario, with a 15 kWh BESS the monthly bill reduces to 114 TLs from 224 TLs corresponding to a 50% reduction with an approximate of 5-year ROI value. As expected, when the load amount increases for the system, the ROI of same BESS decreased since the amount of electricity that needs to be stored decreased.

To continue, Scenario 3 simulates a mixed building with commercial and residential customers. In this case the load value is at the same level as the generation, the amount of electricity that needs to be stored is minimum. This creates a significant reduction in the ROI. A 15 kWh BESS and the PV panels are expected to have 2.5 years of return value.

For the final scenario, a 20 kWh BESS can be utilized because it can supply the load on peak-tariff from the surplus electricity throughout the day and has a 6.7-year ROI value.

To further improve the charging and discharging of the BESS, different charging rates for summer and non-summer seasons have been implemented and the results shows us that a different SoC between 21st of March and 23rd of September, inside the year creates a significant impact on the average electricity bill and the ROI.

The values of ROI have decreased to 4.5 years in Scenario 1, to 4.3 years in Scenario 2, to 2.3 years in Scenario 3 and to 6 years in Scenario 4.

CHAPTER 5

CONCLUSION

This thesis explores the integration of rooftop photovoltaic (PV) systems with shared micro-mobility networks, focusing on utilizing surplus PV energy to charge micro-mobility devices. These devices, available for public use within a designated region, can be picked up and dropped off at specified substations. While the operation of the micro-mobility network is assumed to be managed by a company via mobile applications, this study focuses on evaluating the integration of the micro-mobility system with a PV and Battery Energy Storage System (BESS) framework to support the development of Net Zero Energy Cities (NZECs). Financial and operational aspects of the micro-mobility network fall outside the scope of this research.

By leveraging excess PV energy and implementing a rule-based controller to manage BESS charging and discharging, this study assesses the feasibility of storing surplus energy and optimizing its use. The primary goal is to demonstrate how this integrated approach can contribute to the realization of NZECs, aligning with sustainability and energy efficiency goals.

The research aims to maximize the benefits for building end-users, micro-mobility operators, and the broader community by applying BESS and rooftop PV systems. A rule-based control strategy is utilized, as it offers a practical alternative to optimization-based methods, which require detailed geographical configurations and are more complex to implement. The rule-based control incorporates elements of simple Model Predictive Control (MPC) alongside historical decision data. PV generation data is derived from a university campus, while the load data is synthetically generated using synPRO and ALPG from the University of Twente.

The thesis includes simulations of various test scenarios based on different customer types within buildings, considering both seasonal and non-seasonal control structures. These scenarios cover residential and mixed-use buildings. In the first scenario, a 15 kWh BESS is identified as optimal for residential buildings, striking a balance between cost-effectiveness and performance. The return on investment (ROI) ranges from 1.6 to 10.5 years as the BESS size increases from 3 kWh to 30 kWh.

In a second scenario, which involves buildings with higher overall and peak demand, a larger BESS is recommended. For example, a 10 kWh BESS achieves an ROI of 3 years and 11 months, while a 15 kWh system extends the ROI to 5 years and 3 months.

Another scenario demonstrates that when the load closely matches the PV generation, a 15 kWh BESS yields significant savings, reducing electricity bills by approximately 30%, with an ROI of 2.5 years.

For buildings with higher energy demands, a larger BESS proves more effective. In a fourth scenario, a 20 kWh BESS emerges as the optimal choice, cutting electricity costs by more than half and providing an ROI of around 6 years.

Across all scenarios, the second controller’s adaptive strategies, particularly its ability to adjust the state of charge based on seasonal variations, further optimize both costs and ROI.

Beyond micro-mobility devices, the potential integration of electric vehicles (EVs) within this framework opens new avenues for future work. EVs, with their larger battery capacities, present an opportunity to store excess PV energy more efficiently and manage energy flows within buildings. This expansion would allow for the use of vehicle-to-grid (V2G) and vehicle-to-home (V2H) technologies, turning EVs into both storage solutions and dynamic energy resources. The interplay between EV charging, shared micro-mobility systems, and BESS could further enhance the flexibility and efficiency of energy management within NZECs, creating a more robust and adaptable system.

Achieving net-zero energy buildings is a challenging but necessary step in the fight against climate change. A comprehensive approach to sustainability requires the integration of PV panels, electrified micro-mobility, and the deployment of real-time, rule-based control systems. This approach not only addresses environmental concerns but also promotes economic viability by reducing the reliance on fossil fuels and minimizing the carbon footprint within a context of affordability.

Ultimately, the pursuit of NZECs is about more than just energy production and consumption; it is about constructing a sustainable, stable, and affordable future for current and future generations.

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APPENDIX A

TEZ İZİN FORMU / THESIS PERMISSION FORM

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TEZİN ADI / TITLE OF THE THESIS (**İngilizce** / English) : Assestment Of Cooperatıon Of Photovoltaıcs And Electrıfıed Mıcro Mobılıty In The Concept Of Net Zero Energy Cıtıes

TEZİN TÜRÜ / DEGREE: **Yüksek Lisans** / Master [X] **Doktora** / PhD [ ]

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