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# A Decentralised Peer-to-Peer Energy Trading Platform for Residential Homes

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# Abstract

To achieve a sustainable and low-carbon energy system, it is necessary to develop novel solutions for the way household energy is consumed. Homes that have solar photovoltaic (PV) systems, electric vehicles (EVs), and microgrids can potentially transform the energy landscape by participating in decentralised energy market. All the previous blockchain-related work focuses on the general business use case and management; it does not provide the technical feasibility, bidding strategies and practical value of the renewable market.

Therefore, in this Research, *SolarChain*, a proposed blockchain model for storing and accessing Peer-to-Peer (P2P) transaction in a secured manner. This study demonstrates an experimental blockchain platform developed on Ethereum that is being implemented to exchange electricity. The demonstration replicates a P2P network, including microgrids, solar-powered homes, and Vehicle-to-Grid (V2G) user nodes. User cases for P2P trading, smart contracts, tracking buyer-and-seller exchanges, and comprehensive implementation process information are all included in the implementation. The use of Smart Grids for dynamic pricing to balance supply and demand in microgrids, setting interval periods and token prices, automated and autonomous operation, market clearing prices(MCP), experimentation on a testbed using Node.js and web3.js API, and frontend user simulation with virtual consumers and prosumers derived from benchmarks are notable features.

The proposed architecture is validated using realistic user interface (UI) provides 10 default smart contract buttons that users can utilise to run the simulation and Ethereum Virtual Machine (EVM) environment of Ropten Test Network. The research also looks at the use case for Ethereum's constraints in the application at hand. P2P platforms can lower infrastructure and transmission costs by promoting p2p local energy community can reach cost efficiency and self-sufficiency.


**Keywords**: Blockchain, Ethereum, Prosumers. Energy trading, Peer-to-peer(P2P), Smart Micro-grid, HOMERs, Electric vehicle(EVs), Solar PV.

# Declaration

I, Philip Debrah, declare that the thesis " A Decentralised Peer-to-Peer Energy Trading Platform for Residential Homes " and all its contents are my own intellectual work and research. I further confirm:

- My research degree includes this thesis, which I mostly wrote at Salford University.
- By academic honesty and transparency, I have noted in this thesis if any elements have been submitted for a degree or other qualification at Salford University or any other academic institution.
- I always credit published works, scholarly publications, and other external sources.
- This thesis is my own work and thoughts, save for properly mentioned and attributed quotations.
- I gratefully recognise all the main sources of aid, support, and guidance that helped me write this thesis.
- I've clearly stated other people's and organisations' contributions where this research was done collaboratively.
- This declaration accurately describes my thesis, and any misrepresentation would have major academic and ethical consequences.

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# Table of Contents

# List of Figures

# List of Tables

# Nomenclature

**API-** Application Programming Interface

**BESS** - Battery Energy Storage System- Lead Acid Boiler

**DApps** - Decentralised Applications.

**DERs** -Distribution Energy Resources.

**DSO** - Distribution System Operator.

**DSM** -Demand Side Management.

**DR** -Demand Response.

**DN** -Decentralised Network.

**EE** -Energy Efficiency.

**EVM** -Ethereum Virtual Machine.

**FIT** - Feed in Tarriff

**HOMERS**- Hybrid Optimisation of Multiple Energy Resources

**kWh** - kilowatt-hours.

**FIT PV** - ManCity FITPV

**MCP-** Market Clearing Price

**NRESs**-Non-renewable Energy Sources

**Ofgem** - Office of Gas and Electricity Markets

**OOPS** - Object Oriented Programming Language

**P2P** - Peer-to-Peer

**PoS**- Proof-of-Stake

**PoW**- Proof-of-Work

**PV-** Photovoltaic.

**SCs** - Smart Contracts

**RE** - Renewable Energy

**RETS**-Residential energy trading systems

**SGAM**- Smart Grid Architecture Model

**SmIGen-** Smaller Genst.

**SOC**- State-of-Charge.

**SOH**- State of Health

**TSO**- Transmission System Operator.

**V2B-**Vehicle-to-Building.

**V2G**- Vehicle to Grid.

# CHAPTER 1 Introduction

The traditional approach of relying on huge, centralised energy facilities that heavily depend on non-renewable energy sources (NRESs) is being fundamentally challenged in the quest for a more sustainable and ecologically conscious energy future [1]. The concerns regarding energy loss during transmission and the environmental harm caused by this method have prompted a transition towards adopting renewable energy sources (RESs). This move represents a paradigm shift in energy generation, highlighting the importance of being close to where energy is used and reducing the negative effects on the environment [2]. Harnessing energy from renewable sources and distributing energy production across multiple locations can contribute to a more resilient and environmentally sustainable energy system [3].

With the increasing importance of Distributed Energy Resources (DERs), a distinct group of energy players called "prosumers" is emerging. These forward-thinking individuals or enterprises effortlessly shift between roles of producing and consuming energy, actively influencing their energy impact through Distributed Energy Resources (DER) technology [4]. Nevertheless, the sporadic nature of distributed energy resource (DER) generation presents difficulties for individuals who both produce and consume energy, requiring inventive measures such as energy storage, trading, and connection with the primary power grid [5]. A new and innovative concept known as Peer-to-Peer (P2P) energy trading has arisen, completely transforming the way local energy transactions are conducted inside communities [6].

P2P energy trading enables direct energy transactions between prosumers and traditional customers, creating a localised and decentralised energy exchange [7]. This method obviates the necessity for intermediaries, enabling individuals to engage in negotiations over energy pricing and preferences. Prosumers have the capacity to distribute excess energy to their neighbours, which promotes the principles of energy sustainability and efficienc[8].

Nevertheless, current energy markets face difficulties in adapting to the sporadic character of renewable energy sources (RES) generation. This emphasises the necessity for contemporary market strategies that take into account the geographical aspects of energy supply and consumption. Such approaches are crucial for the seamless integration of distributed energy resources (DERs) into the power grid [9].

Microgrids are geographically compact communities made up of interconnected DERs and loads. They improve energy supply stability and can serve as backup power sources during grid outages [9]. P2P energy trading has been facilitated by the advancement of information and communication technologies, allowing multidirectional energy trades within local areas [8].

The peer-to-peer energy trade, enabled by developments in information and communication technology, encounters obstacles such as data security and privacy concerns. Blockchain technology is being recognised as a promising option to tackle these challenges [10]. The energy sector is currently experiencing a substantial shift towards a more sustainable and decentralised structure, with a focus on local energy production, trading, and consumption [12].

Peer-to-peer energy trading, which facilitates direct transactions without intermediaries, is crucial for improving energy resiliency, encouraging the adoption of renewable energy, and decreasing dependence on centralised power grids[11]. P2P energy trading, which enables individuals and communities to purchase and sell energy directly without intermediaries, is a crucial concept emerging from this transformation. This strategy increases energy resilience, encourages the use of renewable energy sources, and decreases reliance on centralised power grids.

Blockchain networks enable energy customers to make well-informed decisions regarding their energy suppliers and generation technologies, providing a decentralised and transparent framework [12]. Various industries, academic institutions, and researchers are now investigating the potential use of blockchain technology in energy markets and peer-to-peer energy trading. The objective is to create more efficient and decentralised systems. Blockchain technology, characterised by its robust and transparent infrastructure, eradicates the need for middlemen and diminishes transaction expenses, rendering it a highly promising resolution for peer-to-peer energy trading [13].

The integration of renewable energy sources, such as Solar PV and V2G technologies, with a platform based on blockchain technology improves the interchange of energy between prosumers and the grid, hence optimising both systems.

The renewable energy infrastructure in the UK has experienced significant expansion, as households equipped with Solar PV systems are able to sell excess energy and the presence of electric vehicle (EV) chargers enhances the value of houses [14]. The growing implementation of electric vehicles (EVs) is in accordance with the UK government's Net Zero goal, which aims to attain complete elimination of greenhouse gas emissions by 2050. Nevertheless, the extent to which electric vehicles (EVs) can effectively decrease greenhouse gas (GHG) emissions relies on their charging being exclusively powered by 100% zero-carbon sources. This underscores the need of employing intelligent charging solutions [15].

The growing implementation of electric vehicles (EVs) is in accordance with the UK government's Net Zero goal, which aims to attain complete elimination of greenhouse gas emissions by 2050 [16].

Nevertheless, the extent to which electric vehicles (EVs) can effectively decrease greenhouse gas (GHG) emissions relies on their charging being exclusively powered by 100% zero-carbon sources. This underscores the need of employing intelligent charging solutions[17].The projected growth in electric vehicle (EV) adoption to reach 14 million by 2030 requires the implementation of advanced technology and intelligent charging systems to meet the growing demand for power [18]. A substantial corpus of research has been done on the possibility of peer-to-peer energy trading. According to the Rocky Mountain Institute study, P2P energy trading might help American customers save up to $100 billion annually [19].Global development of blockchain-based peer-to-peer (P2P) energy trading platforms, such as Grid+ and Sonnen Community, is underway. These platforms enable homeowners with distributed energy resources (DERs) to easily exchange energy. P2P domestic energy trading systems are becoming a promising mechanism for V2G technology, enabling homeowners to exchange energy within their communities [20].

The energy sector stands to benefit greatly from the substantial potential of blockchain technology, which provides attributes such as transparency, reliability, data permanence, and robust security. Although in its nascent phase, blockchain possesses the capacity to fundamentally transform the energy industry. Nevertheless, there are other obstacles that need to be overcome in order to achieve universal adoption, particularly in the areas of technology, legality, and safety, especially when it comes to peer-to-peer transactions [21, 22].

Furthermore, blockchain technology can modernise the grid by incorporating cutting-edge technologies, equipment, and controls that communicate and collaborate to deliver electricity more reliably and effectively. Because consumers have more access to their data, they can better manage their energy consumption and expenses. The advantage of a modern grid for utilities is Improved security, reduced peak loads, higher renewable integration, and lower operational costs. This research aims to design and implement decentralised energy trading models based on the Ethereum blockchain, enabling homes with solar PV, EVs, and microgrids to participate in P2P transactions using an auto bidding process and impact household energy-efficient systems. The research aims to promote adopting a more sustainable and efficient energy system and encourage individuals to adopt renewable energy practices. As a result, this research will provide technical details describing how a blockchain-based energy trading platform for exchanging solar PV and EV output is designed, developed, and implemented using the open-source Ethereum blockchain application.

### 1.1 Statement of the Problem

There has been a continuous growth in energy consumption in recent years. This increasing demand for power generation has created a new environmental challenge for UK system operators, including the future climate change goal of an 80% reduction in greenhouse energy emissions by 2050 [23]. The UK Government is committed to identifying the key technology solution that brings renewable energy consumption and supporting the delivery of new government policy. Peer-to-peer (P2P) residential energy trading systems (RETS) are a promising mechanism that meets these requirements for V2G technology because homeowners, like peers, can use their distributed energy resources (DERs) at their discretion to trade energy within their community [24].

The following are some of the problems with the current centralized power grid:

- It is inefficient; the average power grid loses about 6% of the generated electricity.
- It is unsustainable; the power grid relies on fossil fuels, a significant source of greenhouse gas emissions.
- It is not flexible. The power grid is not able to adapt to changes in demand.

Energy trading requires high trust between the parties involved, which can be challenging in centralized systems. Blockchain technology can help address this issue by enabling secure, transparent, and immutable transactions. The research can address the problem of lack of trust and transparency in energy trading and demonstrate how blockchain technology can help address this issue.

Energy trading involves complex processes, such as billing and settlement, that can be challenging to manage in traditional systems. Blockchain technology can help simplify these processes by automating them through smart contracts. The research can address the complexity problem in energy trading and demonstrate how smart contracts can help streamline these processes.

A P2P energy trading platform built on the Ethereum blockchain framework can help to create a more efficient and sustainable energy system. The platform would allow consumers to directly trade electricity with each other, bypassing the need for a central utility company. This would lead to several benefits, such as lower energy cost, increased reliability and promoting the use of renewable energy sources.

The economic viability of peer-to-peer energy trading can be a challenge, as it requires a critical mass of participants to make the trading platform viable. The research can address the problem of economic viability and demonstrate how peer-to-peer energy trading can be financially sustainable. Blockchain technology has the potential to modernize the grid by incorporating cutting-edge technologies, equipment, and controls that communicate and collaborate to deliver electricity in a more reliable and efficient manner. In the future, energy management systems will use "peer-to-peer" trading, which lets people who make their own electricity share their extra energy with others, and a smart grid will help distribute it.

## 1.2 Research Aim and Objectives

This study aims to develop a decentralised energy trading model utilising the Ethereum blockchain, thereby facilitating the participation of households outfitted with solar PV systems, electric vehicles (EVs), and microgrids in peer-to-peer (P2P) energy transactions. This will, therefore, advance the comprehension and practical application of sustainable and efficient energy systems.

To achieve this aim, we will undertake the following objectives:

- Design and implement decentralized energy trading model.
- Propose an architectural framework for a decentralised energy trading model on the Ethereum blockchain that incorporates automated bidding for households with solar PV, EVs, and microgrids.
- Identify the impact of blockchain smart contracts to perform and validate energy trade transactions for transparency, security, and immutability.
- Implement modelling and optimisation of renewable resources using Hybrid Optimisation of Multiple Energy Resources (HOMER) to minimise overall costs and obtain economically and technically optimised energy system configurations.

Through the accomplishment of these goals, the research endeavours to make a significant contribution to the rapidly developing field of decentralised energy trading and sustainability by providing useful insights and potential solutions.

## 1.3 Research Contribution

This study's findings can be utilised as a knowledge base for businesses and groups interested in blockchain adoption in the energy sector and EV charging, as well as a foundation for future research studies. *Solar Chain*: is a proposed P2P trading platform that secures energy exchange between PV, EV, and Smart grid.

This research contributes in the following ways to the fields of decentralised energy trading and sustainable energy practises:

- The implementation part is demonstrated step by step process of designing and implementing a blockchain-based platform for Exchange of p2p energy trading platforms. Contributed to the integration of renewable energy and blockchain system.
- A three-layered architecture is described, with an emphasis on the physical, virtual, and application layers. The architectural model plays a critical role in the research methodology by enabling the simulation of automated proposal processing and energy trading. Automatic settlement and energy trading transactions: using auto bidding to eneable P2P transaction for solar PV, EVs and Microgrid integration.
- Proposed *SolarChain* is an innovative blockchain platform that enables secure peer-to-peer energy transactions involving photovoltaics, electric vehicles, and microgrids. The implementation showcases the significant contributions of photovoltaics (PVs) and electric vehicles (EVs) to grid dependability, with a focus on how the flexibility of EV demand enhances grid efficiency.
- Understanding the technical characteristics of the Ethereum blockchain is crucial for the advancement of the SolarChain platform. This study uses smart contracts and a user-friendly interface to create a foundation for secure, transparent, and automated peer-to-peer energy transactions. It greatly enhances the comprehension and implementation of decentralised energy trading systems.

## 1.4 Research Structure

This research has been cautiously organised to provide a clear overview of the scope, objectives, and contributions made by the study. The following chapters provide an overview of the process that will be followed to design, develop, and ultimately deploy a blockchain-based energy trading platform that will allow for the exchange of solar photovoltaic (PV) and electric vehicle (EV) output.

**Chapter One** presents the research introduction, Contributions, aim and objectives.  The grid is undergoing significant changes as energy-consuming technology, such as electric vehicles, is introduced to the system. This research aims to provide technical details describing how a blockchain-based energy trading platform for exchanging solar PV and EV output is designed, developed, and implemented in blockchain applications. Figure 1.2 shows the outline of the research process.

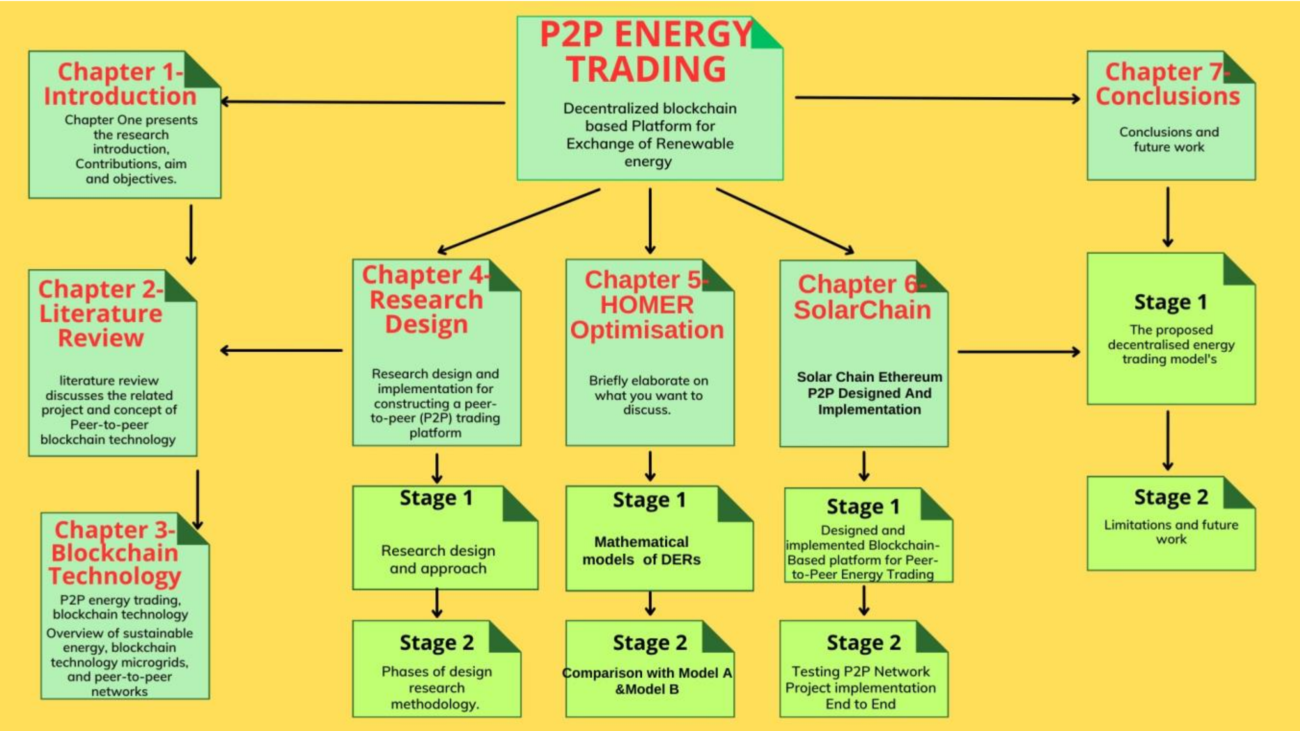



Figure 1. 1 The outline of the research process

**Chapter One**: The first chapter acts as an introduction to the study, taking the reader into the fascinating realm of energy transformation and the dynamic changes taking place in the grid. The growing importance of energy-intensive technology, such as electric vehicles, provides an opening for examining the relevance of this study. This chapter provides a road map for the rest of the study by outlining its overall purpose and its specific objectives. The chapter also highlights the significant contributions to the field of blockchain applications in energy trading that this study has made.

**Chapter Two-** In this chapter, the literature review establishes the context for the research by investigating related projects and delving into the complexities of the UK Electricity market. The focus then shifts to the Microgrid Energy Market, which serves as the theoretical foundation for the remainder of the investigation. Key topics such as renewable energy sources, the United Kingdom's increase in renewable energy, rising energy costs, and the examination of vehicle-to-grid technology

The chapter concludes by discussing extant research gaps, paving the way for the distinctive contributions of this study.

**Chapter Three**- Blockchain Technology- This chapter examines blockchain technology in-depth, commencing with its fundamental concept and tracing its history. The Ethereum blockchain architecture is described, including its decentralisation, advantages, and limitations. Various components of the Ethereum blockchain application are analysed, including Ethereum accounts, Ethereum networks, and Ether. In addition, the chapter examines the Agile development methodology utilised for blockchain applications. The objective is to develop a solid theoretical basis for the investigation. The review of Blockchain technology trading Projects

**Chapter Four**- Research Design and Implementation. This chapter will discuss the research approach, project Setup and Implementation- the implementation of the proposed blockchain P2P energy trading platform. Discussed the design of a blockchain peer-to-peer Technology System architecture for blockchain application. This chapter goes into greater detail about the blockchain infrastructure's architecture, structure, and benefits. The proposed architecture of a decentralised energy trading model based on the Ethereum blockchain enabling homes with solar PV, EVs, and microgrids to participate in P2P transactions. Hybrid Optimization of Multiple Energy Resources (Homers)Simulating the operation of a Micro Grid system over an extended period of time is one of HOMER's primary capabilities. Work Package: Work packages refer to the defined and organised tasks or activities within a research undertaking. They define the activities, deliverables, and timelines required to accomplish the project's objectives.

**Chapter Five**- This chapter explores Homers modelling and optimisation in the context of Peer-to-Peer (P2P) energy trading. Modelling the distribution of energy resources (DERs) within a P2P system is our primary focus. We investigate the mathematical models of distributed energy resources (DERs), analyse two distinct models - Model A (Grid Connection, Solar, and Battery Storages) and Model B (Grid Connection, Solar, EV, and Battery Storages) - and present simulation results for both models. This chapter offers valuable insight into the efficacy and efficiency of various P2P energy trading configurations.

**Chapter Six**- Solar Chain Ethereum P2P Designed And Implementation. This represents a turning point in our process to develop Solar Chain, a blockchain-based peer-to-peer energy trading platform. We transitioned successfully from design to implementation, rigorously tested the platform, established a robust Ethereum development environment, and simulated user interactions. Testing the

*SolarChain* platform end to end: This section will discuss the virtual representation or emulation of a peer-to-peer (P2P) user interface (UI) that allows users to engage with a P2P network is referred to as a simulation of a P2P user interface (UI). This chapter's insights and accomplishments pave the way for Solar Chain's future periods of development and deployment, representing a significant step forward in its evolution.

**Chapter Seven** -Conclusions and future work- This concluding chapter provides critical insights and conclusions drawn from the use of a blockchain interface as a tool in a P2P network, with an emphasis on electric vehicle charging. The prospective benefits of the study for researchers and utility engineers interested in deploying and evaluating blockchain networks for peer-to-peer renewable energy trading are highlighted. Future research directions and areas requiring further investigation are enumerated as well, leaving room for innovation in the dynamic field of decentralised energy trading.

# CHAPTER 2 Overview of Renewable energy

## 2.1 Background

In the first phase of the research, a comprehensive literature review is conducted to obtain a comprehensive understanding of the current state of renewable energy. This review is essential for identifying research deficiencies that must be addressed. The review of relevant literature will cover the following important areas:

## 2.2 The Electricity System and Renewable Energy

The literature study will encompass various crucial aspects pertaining to the present status of renewable energy in the United Kingdom. This study will initially analyse the energy framework in the United Kingdom, encompassing the configuration and functioning of the electrical system, alongside the present condition and advancements in renewable energy technology. Author [25] considered the forthcoming investigation aims to offer valuable insights regarding the contextual factors and obstacles associated with the integration of peer-to-peer (P2P) energy trading within the existing energy framework. Furthermore, the review will examine the fundamental concepts and principles behind blockchain technology, encompassing its decentralised nature, consensus methods, and security attributes. The work by Author [25] will primarily examine the utilisation of blockchain technology within the energy sector, with a particular emphasis on its uses in peer-to-peer energy trading. The research aims to explore the advantages and drawbacks associated with this technology in this specific context. Moreover, the literature review will explore the ideas of energy trading, with a specific focus on the electricity market in the United Kingdom. The energy market in the United Kingdom encompasses both wholesale and retail sectors, wherein the generation of electricity involves the participation of both major multinational corporations and small to medium-sized firms (SMEs). The electrical network is comprised of two distinct components: the transmission network and the distribution network. These networks serve the purpose of transporting electricity over varying voltages and distances. The Gas and Electricity Markets Authority, under the oversight of ofgem, assumes responsibility for the management and regulation of the energy and power markets inside the United Kingdom [26].

The review will additionally examine the extant body of research pertaining to peer-to-peer energy trading platforms. Numerous scholarly investigations have been conducted to examine and deploy peer-to-peer (P2P) energy trading models across diverse settings, including community microgrids, smart homes, and local smart grids. The aforementioned studies have conducted an analysis on the viability, advantages, and obstacles associated with peer-to-peer (P2P) energy trading. This includes an investigation into the possibility of energy loss as well as the requirement for power routing and auditing methods[26]. Additionally, the present study will undertake a comprehensive examination of the involvement of financial participants in both wholesale and retail market performance. Existing research has demonstrated that the inclusion of only financial participants, such as futures contracts, can enhance market performance by effectively matching offer prices with suppliers' marginal costs and anticipating reduced wholesale prices. According to author in ref [27], it can be inferred that standardised futures markets have the potential to serve as effective methods for ensuring long-term resource adequacy within the wholesale market framework.

## 2.3 Energy Trading Concepts

The electricity system is divided into two major components. the electricity value chain, which is concerned with the physical flow of electricity from generation to end consumers, and the trade of power and other related products on various energy markets. The scope of this work will focus on energy trading.

### 2.3.1 The UK Electricity Market

They are wholesale and retail markets in the UK. Traditional electricity is generated through transporting electricity and selling it to customers. There are private organisations that supply their customer with the energy they need. Traditional electricity generation involves large multinationals and small-medium enterprises (SMEs). In large power plants linked to the national transmission network, the bulk of the electricity is generated in smaller power stations connected with the regional distribution network. The electricity network has two kinds: transmission and distribution. Transmission networks transport electricity at high voltages at long distances across the region. Distribution networks run at lower voltages and carry power to homes and businesses from the transmission grid. Energy and power markets are managed by the Gas and Electricity Markets Authority and are controlled by OFGEM. Ofgem's role is, where possible, to protect consumers' interests by fostering competition. Ofgem questions licenced companies in the electricity and gas sector about the returns that companies will make from the monopoly networks and determines changes to market laws [28]. The Figure 2.1 below shows the generation, transmission and distribution of electricity in the UK.

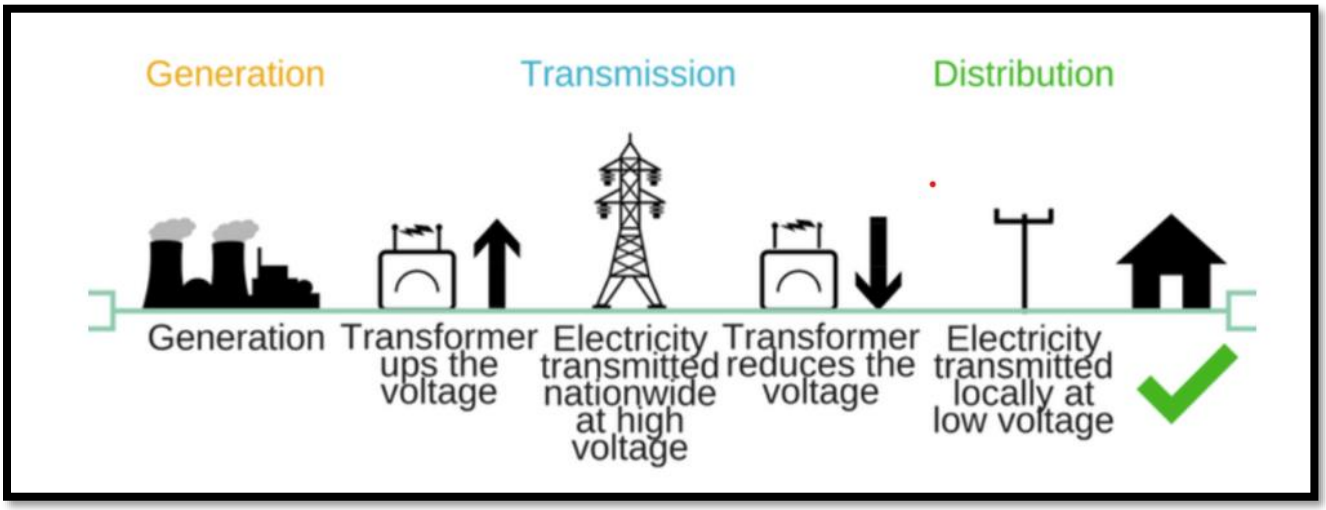



Figure 2. 1 National Grid Electricity Transmission [29]

### 2.3.2 Renewable Energy Source and Micro Grids

There are several advantages for sustainable energy systems when blockchain technology is used with renewable energy sources and microgrids. Many studies have shown that decentralised energy generation and distribution can improve grid reliability, lower energy costs, and cut down on transmission losses compared to conventional power plants.

Researchers have looked into how blockchain-based systems can improve the distribution and utilisation of renewable energy resources. Excess energy generated from renewable sources can be directly traded amongst community members in a peer-to-peer energy-sharing arrangement among prosumers. Energy producers may be fairly compensated through the use of smart contracts and blockchain-enabled metering devices, and consumers can have access to clean, affordable energy.

Figure 2.2 depicts the conventional power supply landscape, encompassing details pertaining to wind farms, power stations, and providers of residential electricity, both with and without solar panels.

Traditional Electrical Supply:

As stated previously, the circuit comprises the following elements: a transformer, rectifier, filter, voltage regulator, and output stage. Utilised in a wide range of consumer electronics, appliances, and electronic devices. Decentralised power plants frequently utilise fossil fuels, including coal, natural gas, or nuclear energy, to produce electricity.

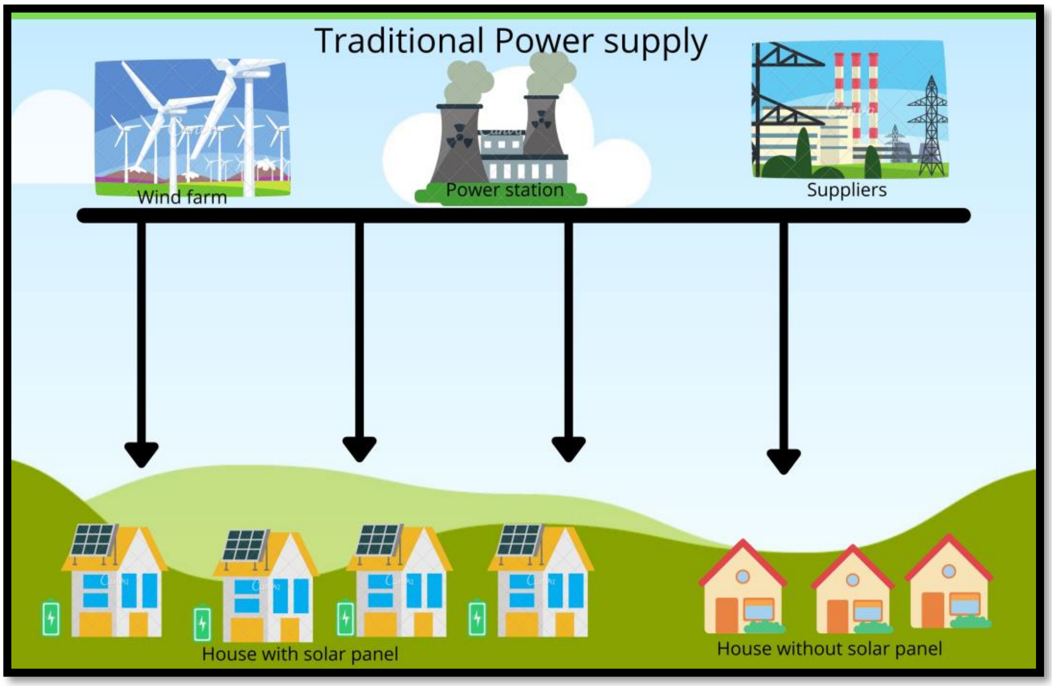



Figure 2. 2 Traditional power supply

Renewable energy, which may be integrated into power systems in many forms, such as active distribution networks and integrated energy systems [30] and microgrids, is playing an increasingly crucial role in redefining the energy industry's future [31]. In this environment, controlling micro-grid markets to maximise renewable energy use is becoming a hot topic in academics and industry. Papaefthymiou and Dragoon (2016) discussed how to convert traditional power systems to renewable-energy-based power systems [32]. Similarly, Hanna et al. (2017) [33]emphasised the importance of policy support; in order to find the optimal operation mode to model the microgrid, Hanna et al. (2017) discovered that the microgrid could only achieve the lowest cost operation and environmentally friendly factors with the support of policies [34]. Li et al. (2018c) provided a microgrid scheduling method with a battery-swapping station for electric vehicles that took into account the real-time pricing mechanism [30]. However, the Author proposes a multi-objective microgrid dispatch technique that takes user experience into account. Kuznetsova et al. (2014) [35] proposed the individual objective of stakeholders to improve the microgrid energy management framework in order to ensure the benefit of microgrid participants. Montuori et al. (2014) introduced the hybrid optimization of multiple energy resources (HOMER) optimization model to evaluate the economic efficiency of a microgrid with a biomass gasification power plant in terms of economic efficiency optimization [36]. Since microgrids require a flexible demand side to simplify system operations (Palensky and Dietrich, 2011), demand response management (DSM) has experienced a renaissance. However, the use of DSM in microgrids does not take advantage of the long-term development of renewable energy sources and reflects socio-economic development needs [37]. Noor et al. proposed a more efficient system based on the blockchain [38].

Li and Li (2019) proposed a microgrid dispatch technique that factored in electric vehicle demand response. Li and Li (2019) provided a game-theoretic model for DSM within microgrid networks augmented by blockchain that realised payment mechanisms and intelligent decentralised control by combining the benefits of DSM and blockchain technology[30].

Over the last decade, the growing use of Renewable energy, such as Vehicle-to-Grid (V2G) and solar photovoltaics (PV) at the grid edge has transformed residential homes into complex energy "prosumers." In a home equipped with V2G, solar PV can both consume and export electricity. As a result, it can participate in a "Transactive Energy" network that involves a peer-to-peer (P2P) exchange of excess electricity. The challenge is to keep track of these transactions and compensate buyers and sellers appropriately. Blockchain has recently emerged as a distributed ledger technology that enables exchanges among participants without the need for a central market entity.

Several research studies look at blockchain-enabled peer-to-peer (P2P) energy trading as a viable alternative to traditional power delivery from a central electric utility. The author in [39] conducts a review of peer-to-peer energy trading projects, several of which use blockchain technology. PowerLedger, Brooklyn Microgrid, Dajie, Share&Charge, NRGcoin, SolarCoin, The sun exchange, Electron, and Enerchain are a few examples.

The electric grid is undergoing a significant transformation as it incorporates more Renewable Energy (RE) into the system to address energy shortages and climate change. Grid operators face a difficult problem since renewables are inherently intermittent. Electric Vehicles (EVs) hold a lot of promise; they have the potential to reduce emissions while also lowering transportation costs.

Due to their battery storage systems that can be flexibly recharged at home, vehicles that use an electric power train as a propulsion system have shown promising development in terms of lowering transportation costs and reducing emissions [40].

According to a recent GTM research [41], roughly 60% of blockchain-based energy projects are now focused on P2P grid networks. These peer-to-peer networks are intended to facilitate energy transfer between network members by obviating the need for a third-party central authority. Individuals who can generate renewable energy at home would be able to sell their extra power, while those with a deficit would be able to purchase energy through a mutually agreed-upon contract. The authors of [42] employ a Blockchain platform to provide a secure peer-to-peer energy trading system in the IIoT. Another piece [43] makes use of Blockchain technology to create a mechanism for exchanging electricity amongst plug-in hybrid vehicles (PHEVs). While a traditional grid network lacks security and transparency when it comes to energy transactions due to the involvement of third-party companies, blockchain-based P2P trading ensures the parties' security and identity privacy.

### 2.3.3 Renewable energy increase in the UK

In recent years, the United Kingdom has made significant progress towards its goal of increasing the use of renewable energy. The nation has committed to aggressive goals to cut carbon emissions, boost energy efficiency, and move to a low-carbon economy. Because of this, renewable energy now accounts for a growing percentage of the electricity produced in the country.

The government's determination to achieve its legally enforceable objective of net-zero emissions by 2050 has been a major factor in the expansion of renewable energy in the United Kingdom. The UK has set intermediate goals of reducing emissions by 78% by 2035 and by 68% by 2030 to get there. As a result of these goals, numerous laws and incentives have been put into place to promote the growth and dissemination of renewable energy systems.

These initiatives have led to a dramatic growth in the use of renewable energy sources in the UK during the past decade. The percentage of electricity generated by renewable sources in 2020 was 43.2%, up from 9.8% in 2010. In the United Kingdom, wind energy is the primary source of renewable energy, producing more than half of the country's renewable electricity. Over 13 GW of solar power capacity has been added to the grid in recent years.

Greenhouse gas emissions have been reduced, and new jobs and economic opportunities have been generated because of the expansion of renewable energy in the United Kingdom. In 2020, the renewable energy industry in the UK was responsible for supporting over 139,000 jobs, and by 2030, that number is expected to rise to over 200,000.

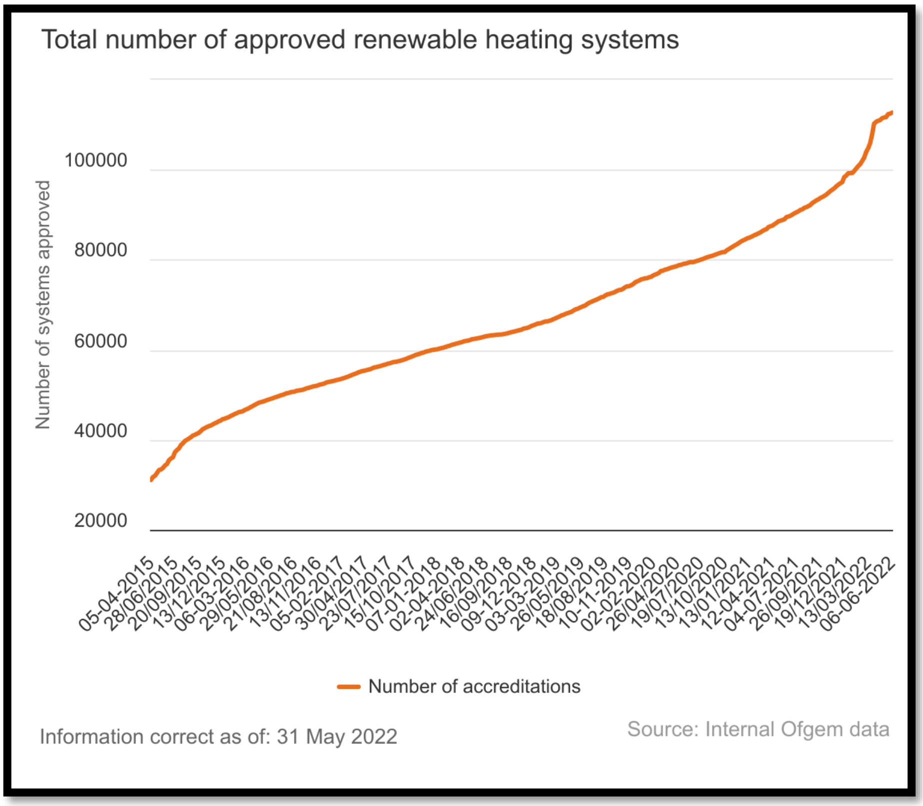



Figure 2. 3Approved renewed heating system [44]

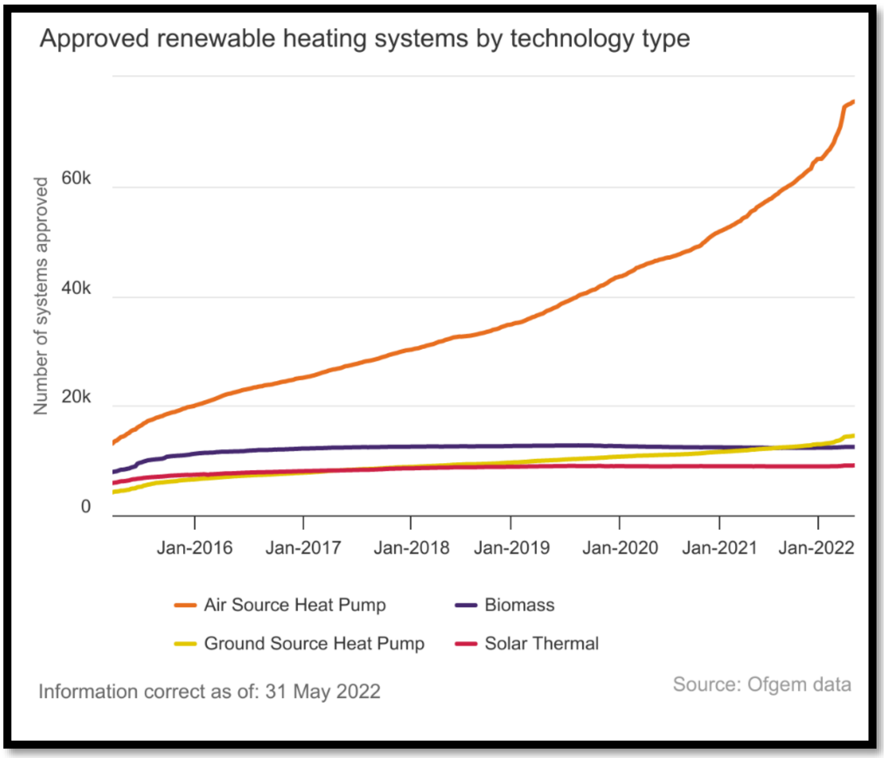



Figure 2. 4 Approved renewed renewable heating systems by technology type[44]

According to ref [45] "The Dynamics of Renewable Energy Transition in the UK: A Comparative Analysis of Biomass, Biogas, and Solar Photovoltaic Systems". The dynamics of the shift to renewable energy in the United Kingdom are examined in this paper, with particular attention paid to biomass, biogas, and solar photovoltaics. The authors argue that the United Kingdom has made substantial progress in deploying renewable energy but that more work is needed to overcome obstacles to adoption and guarantee a smooth transition.

According to the authors of ref [46], Barriers to deployment are identified, as are factors for success, in this analysis of the policy landscape for renewable energy in the United Kingdom. Although the United Kingdom has made great strides in deploying renewable energy sources, the authors argue that more work is needed to address regulatory barriers, public acceptance, and the role of fossil fuels. However, the article examines the evolution of renewable energy in the United Kingdom, with a special focus on wind and solar. According to the authors, the United Kingdom has made great strides in the deployment of renewable energy, but more has to be done to guarantee system integration, deal with intermittency, and speed up the transition to a low-carbon economy.

There has been tremendous progress in the deployment of renewable energy in the UK, according to these studies, but more work needs to be done to remove obstacles to implementation, guarantee seamless system integration, and speed up the shift to a low-carbon economy. Findings stress the significance of public support, policy, and regulatory frameworks for overcoming the difficulties of intermittent and integrated renewable energy.

### 2.3.4 Feed-in-tariff (FIT)

Government programmes known as "feed-in tariffs" (FIT) provide financial incentives to companies that create renewable energy. By assuring just remuneration for the energy that renewable energy sources produce and supply to the grid, FIT schemes seek to promote the adoption and advancement of these sources [47].

The FIT scheme can be incorporated into the proposed system to encourage the production of renewable energy and make it easier for it to be included in the energy trading process[48]. The system is open to producers who produce power from renewable resources like solar, wind, or hydro[49]. They might have installed renewable energy systems in their homes, places of business, or public spaces. The rates at which generators of renewable energy are compensated for the electricity they deliver to the grid are set by the government or regulatory body. To promote the creation and expansion of renewable energy projects, these tariffs are often higher than the going market rates.

According to ofgem [47], Householders receive compensation under the Feed-in Tariff scheme (FITs) for the electricity produced by qualified installed systems such as solar PV, wind, hydro turbines, or micro CHP. You are not impacted by the closing of the programme if you already have an eligible installed system for which you are getting FITs payments. As before, you will continue to get FITs payments. Any eligible installation utilising one of the available technologies may apply for accreditation:

- Photovoltaic (PV) solar energy
- Hydro: small-scale combined heat and power (Micro CHP)
- Anaerobic symbiosis (AD)
- Installations could be as large as 5MW (or 2kW for micro CHP).

There are two different types of FIT participants: FIT generators—owners of accredited installations—and FIT licensees—licensed electricity providers who submitted applications and paid FIT for the electricity used by recognised installations.

**Ofgem's function**

The FIT scheme is jointly administered by Ofgem and the FIT Licensees. A sizable percentage of the daily administration of the plan is handled by the FIT Licensees, including:

Paying for FIT reading metres, inspecting them, and handling complaints and updating generator details. In addition to managing the criteria for sustainable fuelling and installing AD, Ofgem is responsible for managing the databases of all approved installations, the Central FIT Register, the Renewables & CHP Register, and the publication of statistics. Some generators receive considered export payments, which estimate that export represents a specific percentage of generation rather than being based on export metre readings. The amount of generation that is deemed to be exported each year is decided by the Secretary of State for BEIS.

**Solar power tariffs**

There are three main bands of tariff rates for solar PV installations: higher, midrange, and lower. Whether the Energy Efficiency Requirement for the building to which the installation is wired has been satisfied and whether the owner is categorised as a multi-site generator influence which tariff rate an installation receives:

- Higher: The owner is not categorised as a multi-site generator, and an Energy Performance Certificate (EPC) of level D or higher was given prior to the installation's commencement date.
- Middle: The owner is categorised as a multi-site generator, and an EPC of level D or higher was obtained prior to the installation's activation date.
- Lower: Prior to commissioning, no EPC of level D or above was obtained.

Regardless of the date of commissioning, this three-band structure only applies to Solar PV systems that were certified after April 2012. It does not apply to other technology types.

The effects of peer-to-peer (P2P) commerce inside a local community and the Feed-In Tariffs (FIT) programme. Energy bids and smart contracts will be stored using blockchain technology in the proposed system, which attempts to establish a decentralised system.

The integration of Feed-In Tariffs (FIT) programmes with blockchain-based peer-to-peer energy trading platforms is the subject of research by Marangon et al. (2019). According to the study, FIT programmes can encourage the use of renewable energy sources and, when used in conjunction with decentralised systems, can provide fair compensation for energy producers while encouraging the use of green energy sources [50].

The impact of FIT policies in decentralised energy trading systems is covered in a paper by Li et al. (2019). It emphasises how FIT programmes can aid in overcoming market obstacles, promote investments in renewable energy sources, and promote the expansion of decentralised energy markets. The system attempts to use blockchain to address issues with efficiency, cost-saving, and the promotion of renewable energy usage. The integrity of the system is protected by the decentralised nature of the blockchain, which makes sure that energy transactions recorded on the blockchain cannot be changed or interfered with [51].

Energy transactions can be carried out directly between participants without the use of middlemen by utilising a decentralised system. This direct peer-to-peer engagement may help to cut costs and inefficient transactional processes. Implementing a decentralised system can aid in cutting expenses related to conventional energy market arrangements. Unneeded fees and costs can be reduced by eliminating intermediaries and permitting direct transactions.

### 2.3.5 The Rise of Energy cost in the UK

According to Ofgem, From January 2015 to November 2022, the monthly average electricity costs in Great Britain based on day-ahead baseload contracts fluctuated due to a variety of factors such as variations in demand, supply, fuel prices, weather conditions, and government regulations [52].

According to ref [53], the average power price in the United Kingdom in January 2015 was roughly 44.2 GBP per megawatt-hour (MWh). In the first half of 2015, prices remained relatively stable, with a slight increase in June to around 47 GBP/MWh. Prices began to fall in the second half of 2015, reaching a low of roughly 35 GBP/MWh in December, owing to lower demand during mild weather and more renewable energy supply [54].

Prices in 2016 remained low for the first half of the year, averaging around 32 GBP/MWh in June. However, prices began to rise in the second half of the year as a result of increased demand during cold weather and lower wind generation. For the entire year, the average electricity price was around 38.6 GBP/MWh.

Pricing rose further in 2017 as a result of various causes, including higher petrol and carbon pricing, less nuclear availability, and decreasing wind generation. The average price was around 44.4 GBP/MWh for the year, with a peak of around 66 GBP/MWh in November due to a combination of low wind and solar power, unanticipated outages, and increased petrol prices.

In the figure below, According to the ofgem, the price evaluation of over-the-counter trade carried out by a third-party Price ing Agency is where the data for the period of time up until February 28, 2021, may be found. The data will start coming straight from brokers as of March 1, 2021, and it will be an average monthly price that is weighted by volume.

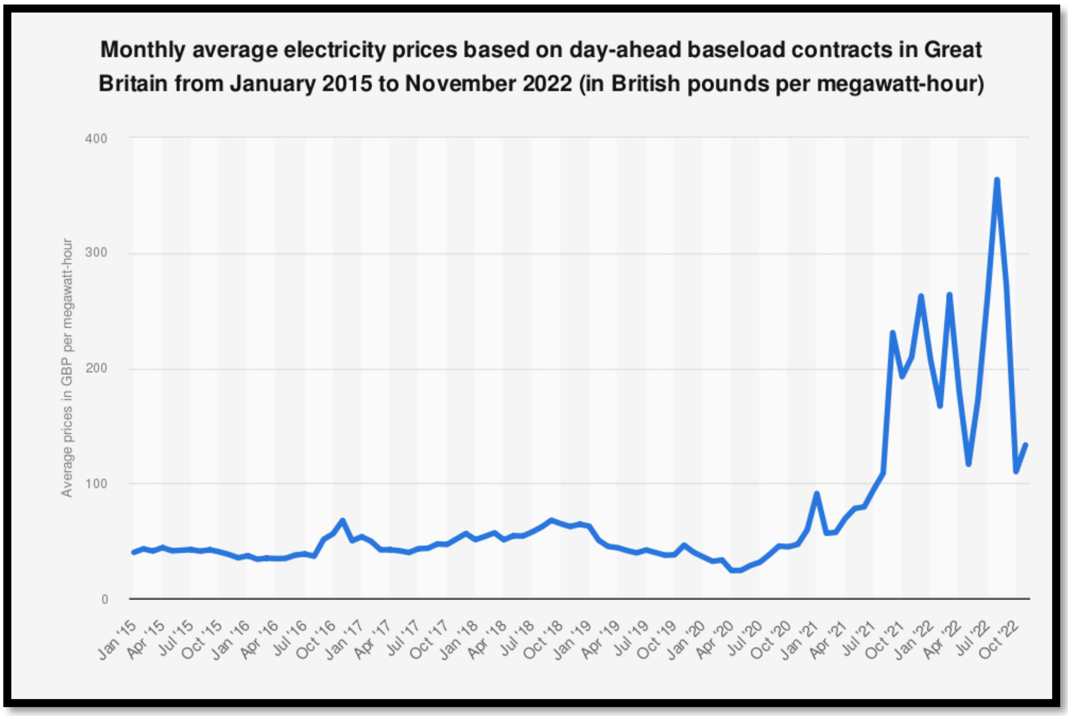



Figure 2. 5 Monthly average electricity prices based on day-ahead baseload contracts in Great Britain from January 2015 to November 2022 [55]

### 2.3.6 UK household's annual electricity consumption

Assumptions: According to Ofgem, the typical UK household's annual electricity consumption is roughly 3,800 kWh. According to official estimates from Ofgem, the average power bill in the UK in 2021 was only £764, but it was close to £2k in 2022. The typical household's energy price guarantee is now £2,500 per year, but this does not mean your energy payments are capped at £2,500! The cap does not apply to the total amount paid; rather, it applies per kWh (unit cost). As a result, the £2,500 'limit' applies solely to households with normal usage. Those who use more will have to pay more than £2,500 each year [44].

Table 1  UK household's annual electricity consumption

| Consumer ID | Electricity Consumption (kWh/year) |
|---|---|
| **1** | 3,800 |
| **2** | 3,800 |
| **3** | 4,000 |
| **4** | 4,200 |
| **5** | 3,500 |
| **6** | 3,500 |
| **7** | 3,900 |
| **8** | 3,900 |
| **9** | 3,700 |
| **10** | 3,700 |

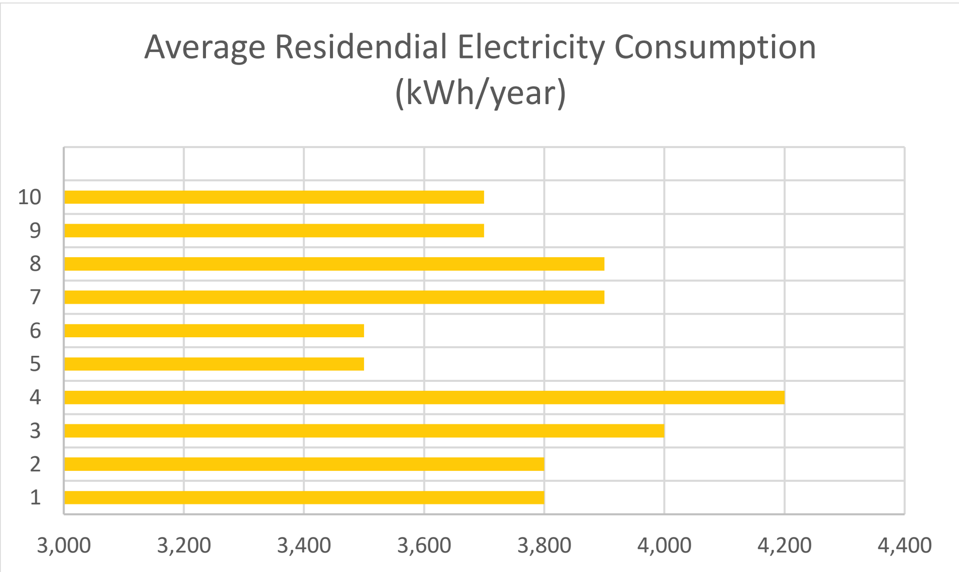



Figure 2. 6 Estimated previous energy consumption of ten local residential consumers in the United Kingdom

As the table shows, the average cost of energy in the UK has been slowly rising over the last few years. In 2015, the average cost per kWh was 13.50 pence, but by 2021, it had risen to 18.1 pence.

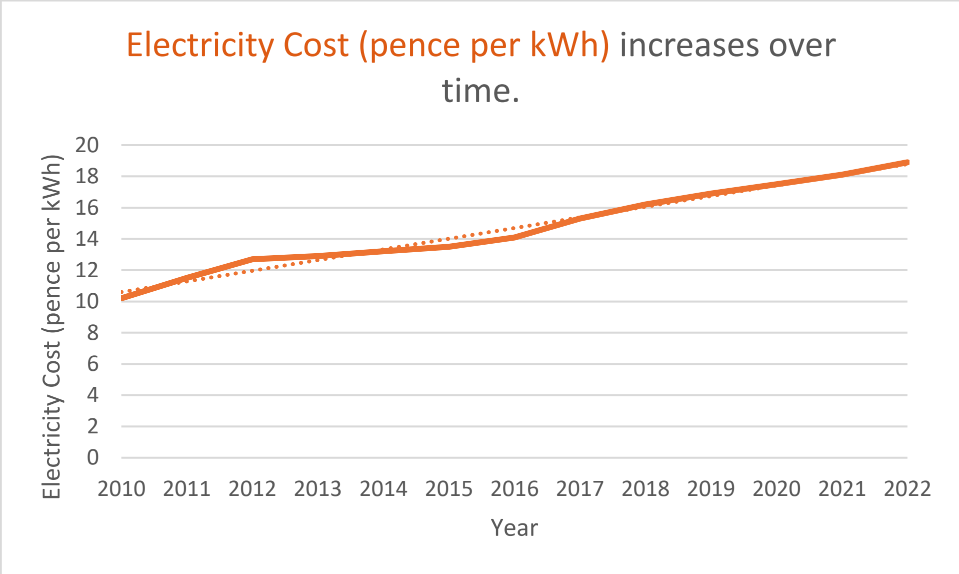



Figure 2. 7 The average cost of energy in the UK

### 2.3.7 Vehicle-to-Everything(V2X) technology

The term "vehicle-to-everything" (V2X) refers to a collection of technologies that allow the energy stored in the battery of an electric vehicle (EV) to be exported and used in a home, by other buildings, or to assist in the balancing of the electricity grid. V2X is a collective term for these technologies. "Bi-directional chargers," which can both charge and drain the battery in an electric vehicle, are essential for V2X [56]. The research will focus on Vehicle-to-Grid (V2G) Charging.

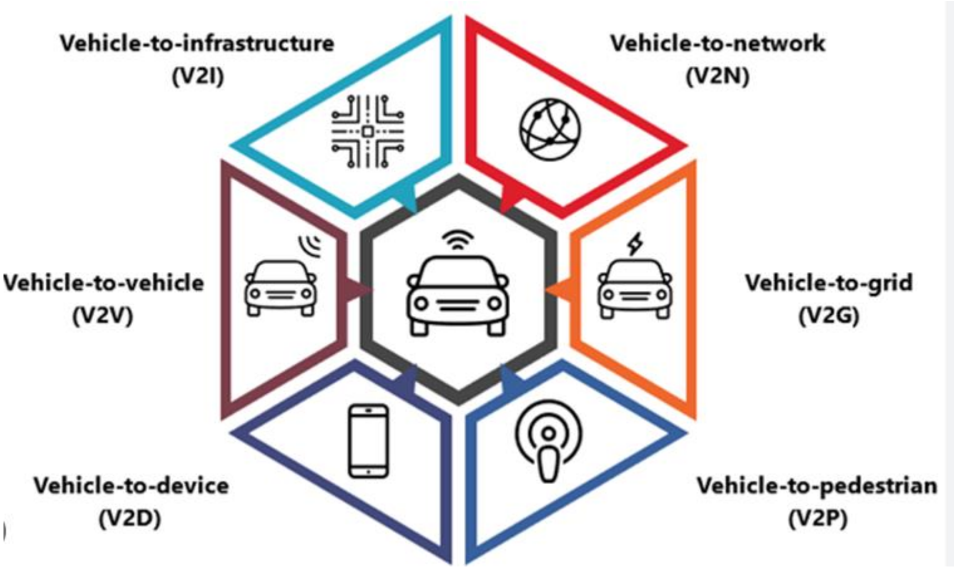



Figure 2. 8 Vehicle-to-everything (V2X) technology [57]

There are types of Vehicle-to-Everything (V2X) technology; depending on where the energy from the electric vehicle is used, various terminology is used to represent use cases for V2X technology. V2X, or Vehicle-to-Everything, refers to communication technologies that enable vehicles to communicate with their surroundings, including other vehicles, infrastructure, pedestrians, and the cloud. In terms of charging, there are several types of charging that can be enabled through V2X. Examples include the following [58, 59]:

- Vehicle-to-grid (V2G)
- Vehicle-to-House: V2H
- Vehicle-to-Building / Enterprise.
- Vehicle-to-Vehicle: V2V
- Vehicle-to-everything (V2X)

Vehicle-to-Vehicle (V2V) Charging: This refers to the transfer of energy between two vehicles. For example, if one vehicle has excess battery capacity, it can transfer some of that energy to another vehicle that needs it.

Vehicle-to-Infrastructure (V2I) Charging: This refers to the transfer of energy between a vehicle and a charging station or other infrastructure. The vehicle can communicate with the infrastructure to determine the availability and compatibility of charging options.

Vehicle-to-Cloud (V2C) Charging: This refers to the use of cloud-based services to optimize charging. For example, a vehicle could communicate with the cloud to determine the best time and location to charge based on factors such as energy prices, traffic conditions, and the availability of charging stations.

Vehicle-to-Grid (V2G) Charging: This refers to the ability of a vehicle to not only draw energy from the grid but also to feed energy back into the grid. This can help to balance energy demand and supply and enable more efficient use of renewable energy sources.

Wireless Charging: This refers to the ability of a vehicle to charge wirelessly without the need for physical cables. This can be enabled through technologies such as inductive charging, where the vehicle is charged by placing it on a charging pad. V2X communication can be used to optimize the charging process and ensure that the vehicle is properly aligned with the charging pad.

### 2.3.8 Vehicle-to-Grid (V2G)

The V2G and G2V technologies have evolved over the last few decades, resulting in numerous benefits for residential communities and edge energy providers. Besides its application in solving the problems of power shortages and satisfying the peak energy demand during specific hours, it also has a lot of other advantages. Some of the most prevalent benefits of V2G/G2V are discussed in the coming sections: Almost all industries, factories, and economies rely on energy to function. If such entities are deprived of energy for even a short time, it can lead to a crisis of finances, thus leading to much more damaging problems. The most important application of V2G/G2V technologies is the conservation of energy in the smart grid, traded from the edge energy providers in the form of electric vehicles when it is most needed. During the pandemic, the world at some point faced an energy crisis when the prices of gas and coal dropped and then suddenly increased due to demand and supply issues. This has not only affected electricity but also made many businesses unprofitable, and their finances plunged to the ground[60]. To cope with such unpredicted events, the V2G/G2V can become the only saviour here by providing backup power when it is needed. Power shortages are not limited to the pandemic; unexpected problems can occur at any time and cause significant damage to the economy. Traditionally, the peak demands for electricity are met by coal-powered plants and gas-powered plants owned by public utility companies. However, with the concept of V2G technologies, this is not the case. Instead of establishing plants, the peak demands are satisfied by measuring simple frequency measurements and dynamic load levelling whenever needed [61]**.** The loads are balanced through "valley filling" and "peak-shaving". Valley filling is charging the electric vehicles at night when the demand from the consumers is not that high, while peak shaving is the sending back of the power to the grids when demand is high from consumers of electricity.

There is no doubt that the number of electric vehicle users has increased tremendously compared to a few decades ago, and it keeps on rising. Because most electric vehicles are used in cities, driving an electric vehicle is more cost-effective than driving a traditional commuting engine in cities. In fact, Los Angeles is considered the leading city in the world in terms of electric vehicle sales. It has nearly 100,000 EVs, more than any other city in the world [62]. The V2G/G2V technologies propose an energy trading system for edge providers of energy in exchange for money for the energy they are not even using most of the time. This, in turn, will eventually reduce the prices of electricity in general residential areas by having a sufficient supply of energy stored in the smart grids powered by all these EVs. This can also be considered a kind of financial incentive to attract more and more electric vehicle users to join the fleet and grow it.

Most modern cities are facing the problem of increasing motorization. It's worth noting that, according to recent research, the global number of motor vehicles is likely to reach over 1.3 billion by 2024, up from 1.2 billion in 2020 [15]. Due to the attractive incentives of the V2G and G2V technologies, it is likely that it will attract more people to shift toward electric vehicles. In fact, it can become a common financial business source, like other businesses, for many people. Consequently, this will lead to the eradication of traditional mechanical engine vehicles, which are considered a common source of environmental pollution. Eventually, it is less doubtful to say that V2G/G2V can ensure an environmentally friendly system to tackle energy problems.

Besides the many advantages of V2G/G2V technology, it also has some drawbacks and challenges that scientists are trying to minimize. Some of the most common drawbacks of V2G are discussed below:

Electric vehicles are equipped with lithium-ion battery cells that are repeatedly charged over their lifespan. Since batteries have a shelf-life and a limited number of charging cycles, the lifespan of a battery can be affected by repeated charging and discharging at charging platforms. Therefore, electric vehicles connected to the V2G/G2V platform need a proper algorithm and method for charging and discharging operations for good battery life. However, some studies have shown that using electric vehicles for smart grid storage can improve their lifespan[63]. Moreover, another common problem is the loss of energy during the process of charging a battery system. After that, the returning energy to the grid, which typically involves inverting DC to AC, results in energy losses. If these losses are factored in for the cost savings, a considerable amount of financial savings can be analyzed and minimized.

Another finding suggests that V2G has a massive effect on the grid's peak times. Whenever a huge number of electric vehicles are charged or discharged, the utilities' peak load rises. There is an imbalance between utilities' supply and demand for electricity because of the unmanaged charging process of EVs. This drawback of V2G is also the focus of the research to be done. The problems that arise from uncontrolled charging may result in far more devastating issues[64].

Previously, the researchers concentrated on putting the V2G platform idea into practice for a variety of applications. This section will present a broad, evidence-based, and supporting review of existing V2G energy trading systems that leverage blockchain peer-to-peer solutions to cut energy expenditures. According to the latest electric vehicle consumer  2021 [65], the sale of electric vehicles has grown exponentially over the past ten years; it is believed mileage driven from 100 miles has increased to 250 miles a week. Realizing the importance of V2G in being a game-changer for energy crises in residential areas, the researchers have worked on explaining numerous advantages of the V2G platforms. However, there is a slew of issues to address as well. Mukesh Kumar *et al.* have presented their findings regarding the advantages as well as the challenges associated with V2G/ G2V platforms [66]. The authors have clearly explained the major role of the V2G platform during the peak time hours consumption of residential areas to handle energy crises. Moreover, Harun Turker *et al.* research explained how the owner of the vehicle could benefit from the leftover battery charge that he isn't utilizing normally at a superior energy rate using Housing Peak Shaving Algorithm (HSPA) [67]. Only in bidirectional V2G service the power grid utilizes an excessive amount of energy from Electric Vehicles (EVs). This service's main purpose is to flatten the grid profile by "load levelling" and "peak load shaving" for a small duration during the daytime when it is economical to take supplies from Electrical Vehicles. The advantage of this V2G system is to ease the load on power system components and a disciplined way to utilize V2G services for its best. However, the V2G/G2V technologies in terms of EV owners and grid operators come with the problems of battery degradation, life cycle losses, energy losses, and huge investments.

In another research, Ref [68] presented the advantages of V2G series services in the form of ancillary services, active power support, backup energy for the home, and reactive power compensation [69]. Tu Yiyun *et al.* illustrate the ancillary services into two main categories: spinning reserve and power grid regulation [70]. The V2G (Unidirectional) manages the EV's charging pace to deliver the load exclusively as "ancillary services." To provide auxiliary services, numerous electric vehicles and aggregators are linked together. On the other hand, to maintain the frequency to meet the generation and load demand, the power grid regulator is used. The spinning reserve has a fast response that responds in 10 minutes for compensating the outage of generation.

Another finding by Awais Hashmi and Muhammad T.G elaborates that G2V/ V2G affects the primary contemplation of an electric system, including dependability, misfortunes, structural constancy, and effectiveness. Similarly, more advancements in V2G technologies create testing problems such as battery abasement [71]. The examinations conducted by Awais Hashmi and Muhammad T.G. also lightened up the financial points of interest regarding V2G innovation relying upon charging procedures and vehicle conglomeration. Furthermore, the challenges are not limited only to the platform's physical aspects, but V2G/G2V platforms are susceptible to more serious threats. Christos Tsoleridis *et al.* discussed all the issues and challenges related to the communication and protocols used at V2G/G2V platforms [72]. Christos and his associates described the technical challenges in several parts:

1) Physical Layers: prone to doppler effect, fading channel interference, and RF effects.
2) MAC Metrics is relative to VANET's: access delay, deliverance delay, overhead, and access fairness.
3) MAC Layer: QoS issues, hidden terminal and VANET's dynamic nature
4) Requirements of V2G communication: bandwidth, effective radius, and Latency.
5) Security threats: i.e., authentication protocol
6) Routing Protocol Challenges
7) Wireless Charging: wireless charging efficiency, distance fine-tuning, On-the-fly charging, and ease of use.

Christos *et al.* have also presented other issues, naming them macroscopic V2G-associated issues in their research, along with discussing other open-research issues such as ancillary services, economy, compensating intermittency of renewable energy generation, and battery life[72]

## 2.4 Existing Gaps in Peer-to-Peer Trading Platforms

The overview of relevant work on peer-to-peer trading shows that Blockchain is an infant and building trial project in the energy sector. The progress in the financial sector has been explored in the growth stage [73]. Many academic researchers and organizations are investigating blockchain innovation in the energy sector. This growth in interest is mainly because blockchain technology can support business decision-making, reduce transaction costs, and improve transparency and efficiency.

All the previous blockchain-related work focuses on the general business use case and management; it does not provide the technical feasibility, bidding strategies and practical value of the renewable market. The research goal is to Implement a peer-to-peer blockchain renewable energy trading platform using Ethereum open-source. As a result, the purpose of this paper is to provide technical details describing how a blockchain-based energy trading platform for exchanging solar PV and EV output is designed, developed, and implemented in blockchain applications. This research examines whether the local energy community can reach cost efficiency and self-sufficiency.

The authors in reference [74] proposed a solution on how energy consumption and electricity cost are optimized using home energy management (HEM), and the demurrage mechanism benefits the local community by providing sufficient energy. A dynamic pricing model and HEM system are introduced to increase economic benefits, reduce electricity costs, and enhance energy consumption at peak hours. The scheduling algorithm was applied with the P2P pricing model and demurrage at peak hours. However, the proposed model does not consider penalty policy and issues of the creation of rebound in an off-peak hour.

The author in reference [75] addresses the challenge of tracking energy transactions in a peer-to-peer network and the lack of technical implementation of blockchain-based P2P trading platforms. In the research, a blockchain laboratory scale was presented using Hyperledger- an open-source collaborative effort. It defines participant, asset, energy transactions and smart contracts on a blockchain trading network to exchange solar energy. The author, in reference [75], presented how blockchain technology allows the record-keeping of all complex transaction and operation data in exchange for excess renewable energy output (kWh).

The author, in reference [76], conducts a systematic literature review on existing works and commercial projects. The research describes the design and technical approach of a blockchain-based trading platform in Switzerland. It outlines the real-world implementation, and the findings provide the guideline for integrating decentralized energy resources (DER).

The work proposed in reference [38] enhances the micro-grid network with blockchain to handle a payoff utility and dips in the load profile caused by supply restrictions. The author uses the game theory approach for demand-side management to reduce the peak-to-average ratio to benefit both individual users and the electricity grid system. The game theory approach illustrated the need for participants and helped to explore the diversity of load profiles. The gap in the study suggested adapting the methodology to combine with previous studies in micro-grids, which are supplied by hybrid renewable energy to capture a wilder consumption in the grid. The impact of DSM on load-shedding events can be studied. However, energy and profit optimization are not considered.

In reference [77], the study proposed a blockchain-based application and continuous double auction (CDA) mechanism in an electricity transaction mode for microgrids. In the study, the Microgrid market allows prosumers with a distribution grid (DG), independent DG operators, and consumers to trade in the same market through the CDA mechanism. An aggressive adaptive strategy is used to adjust price fluctuation in the CDA market. However, there is less flexibility to change the quality of the CDA bidding process. The literature in [78] has highlighted the impact of residential energy management systems in addition to renewable energy sources (RES), electric vehicles(EVs) and storage systems.

According to Zhang et al. [79], a peer-to-peer energy trading platform can improve the local balance of energy generation and consumption. The trading is supported by a simulated energy trading platform, which separates peak and off-peak market intervals. A variety of peers can submit their bids for each DER. Blockchain technology is used to enable the P2P electricity market through the smart contract, which is used to verify transactions between peers.

In recent years, they have been a concern about increasing the efficiency of energy globally. Sustainable programmes make it more important for Energy companies to increase concern toward climate change and zero carbon emission. This has led to the rise of renewable energy – moving away from centralized generation facilities toward decentralized energy generation. (Sustainable Technologies)[80]. This innovation in the energy sector brings about a blockchain-based transactive system to manage the growth of smart generators, distribution networks and devices on the grid.

The Author in Reference [24] suggested in their study focusing on developing a permissioned blockchain-based for residential communities to enable individual homeowners to select bidding their own energy on distributed energy resources (DERs). The suggested solution is built on the permissioned Hyperledger Fabric platform, where all energy bids are stored on a decentralised ledger, and a smart contract is utilised to run a double auction mechanism to dispatch the homeowner DERs. The proposed system is validated by running simulations on an eight-home community using real-world data, as well as deploying it to a Canadian microgrid and benchmarking the smart contract execution time. However, the monetary incentive for individual proprietors to participate in demand response is not considered.

In Reference [81], the authors presented an NRG coin paradigm, also referred to as a unique decentralised digital currency. The idea enables prosumers to sell locally generated renewable energy via a digital currency organised around the market paradigm of buyers and sellers of green energy in a smart grid. The authors of Reference [77] described an adaptive aggressive strategy for a microgrid based on a blockchain-based Continuous Double Auction (CDA), offering a novel perspective on the energy market. However, different bid combinations may have varied initial circumstances, and the CDA bid process provides insufficient flexibility for changing the bid quantity. Similarly, in Reference [82], the authors demonstrated a secure credit-based payment system by shortening the time required for energy chain transaction confirmation in a permissioned blockchain-based Industrial Internet of Things (IoT). Reduced wait times result in faster electricity trading and more frequent responses. Additionally, the authors employed an optimal pricing method to optimise bank utility credit-based loans by utilising Stackelberg game theory.

In Reference[43], the authors suggested a P2P Electricity Trading system with a Consortium Blockchain (PETCON) model for secure private P2P energy trading between plugin hybrid electric vehicles. The study concentrated on developing trust and defended the user's privacy by utilising the anonymous nature of blockchains. Reference [83] proposes a method based on the perceived power quality of a certain economic category. However, the proposed paradigm ignores security concerns, data leaking, and single points of failure. The authors of Reference[84] sought to establish a decentralised and secure transaction in the smart grid by utilising blockchain technology. Participants in the research negotiate the trading price anonymously and conduct secure transactions via anonymous, encrypted message streams and multi-signature transactions. The suggested work differs from current research in that it actively encourages or allows all prosumers to become sellers and self-sufficient consumers during peak energy generation hours. Similarly, the authors of Reference [85-87] proposed a system of distributed energy trading to promote peer-to-peer electricity sharing between prosumers. The author in [87] suggested that the model consists of two levels. The agent coalition mechanism is presented in the first layer to enable prosumers to form a coalition and negotiate energy trading. The second layer proposes a blockchain-based settlement mechanism for transactions.

Reference [88] proposed a distributed solution for controlling Demand Response (DR) devices in a smart grid scenario. Grid elements are connected with the blockchain framework for smart contracts to ensure the verification of DR agreements, the programmatic description of predicted energy flexibility levels, the balance of energy production and demand, and the validation of DR agreements. The author in [89] described a distributed, scalable, and secure blockchain-based network for coalition structure formation and microgrid energy trade. However, negotiating the trading price between the parties is challenging. Similarly, the research in Reference [90]  intended to develop an energy trading model that would enable the sustainable exchange of energy ecosystems between consumers and prosumers of smart houses. However, the optimization of energy and profit is not considered. The work described in Reference[38] not only reduces the peak-to-average ratio, which benefits the grid but also smooths the profile load dips induced by supply restrictions. Additionally, the paper offered an upgraded blockchain approach for implementing a distributed microgrid network that manages micropayments as well as energy and information sharing. Additionally, a noncooperative theoretical game is proposed for a Demand Side Management (DSM) model including storage components.

The analysis identified privacy as a significant barrier to client participation. In Reference [91], the authors proposed an Internet of Things (IoT) system to track electricity flows as well as a blockchain platform to eliminate the need for a centralised body. It enables LEM to manage dispersed energy transfers without relying on central control. On the other hand, a novel approach to the architecture of smart city networks is offered [92]. The architecture incorporated the advantages of blockchain technology and the upcoming Software-Defined Networking (SDN) technology (SDN). Rapid development in the volume and quantity of connected IoT devices introduced new issues, such as bandwidth constraints, scalability, privacy, and high latency in the current architecture of smart city networks. By using blockchain technology and segmenting the design into core and edge networks, the current restrictions are significantly decreased. However, several challenges remain unaddressed, including memory scalability, excessive latency, and efficient edge node deployment. Reference [75] proposes an intriguing lab-scale implementation. To facilitate solar energy sharing, this framework is built on the Hyperledger fabric blockchain platform. In another work [93], the authors conduct a survey on the principles of distributed energy trading in a smart grid. The authors highlighted the benefits of distributed energy trading and the rationale for its adoption, the technology required to build these frameworks, and a review of previous literature work. The authors in ref. [94, 95] defined seven microgrid electricity market principles and evaluated the Brooklyn Microgrid against them. The authors designed and modelled a local power market with a more realistic emphasis on a private Ethereum blockchain that enables users to trade locally generated energy on a distributed and decentralised exchange system without the intervention of a control authority. However, methods for efficient allocation and pricing are not devised.

The author of  [96] proposes a four-layer architecture for peer-to-peer energy trading, which includes a power grid layer, an information and communication layer, a control layer, and a commercial layer. This model is based on the three-dimensional Smart Grid Architecture Model (SGAM). The first dimension addresses the time-dependent nature of peer-to-peer energy trading, in which grid energy users submit bids. After a period of time has passed, the bids are settled by connecting a peer (prosumer) to another peer (consumer). The second step is energy exchange, in which power is transferred between two agreed-upon peers. Finally, the final procedure is payment, in which peers trade funds based on the amount of energy utilised at an agreed-upon price. The second and third dimensions define the P2P network's size and layer structure. The SGAM framework makes use of the blockchain as the information and communication layer. The work didn't consider the development of a bid accept/ rejection system and usage of energy storage in the simulation of p2p bidding.

The work in [24] Residential energy trading systems (RETS) allows homeowners with distributed energy resources (DERs) to engage in virtualized energy markets, potentially lowering residential communities' peak demand. Blockchains are critical enablers of RETS because they provide a decentralised, self-governing network that alleviates privacy and transparency problems. However, additional real-world case studies are required to assess the techno-economic sustainability of blockchain-based RETS in order to increase their positive adoption. Thus, this study creates a permissioned blockchain-based RETS that enables homeowners to choose bidding tactics that take into account their DERs' specific preferences and then evaluates the influence of the bidding methods on lowering the community's peak demand. The suggested solution is built on the permissioned Hyperledger Fabric platform, with a decentralised ledger storing all energy bids and a smart contract executing a double auction procedure and dispatching the homeowner DERs. The proposed system is validated by simulations on an eight-home community using real-world data, as well as through deployment on a Canadian microgrid where smart contract execution time is benchmarked. The work didn't consider P2P trading between EVs and homeowners to further reduce the peak demand of the entire community.

The authors in ref [75] focus on a laboratory-scale implementation on residences equipped with rooftop solar photovoltaic panels that may both consume and export electricity. As a result, it can engage in a "Transactive Energy" network that facilitates peer-to-peer (P2P) trading of surplus electricity. The difficulty is in tracking these transactions and compensating buyers and sellers appropriately. Recently, blockchain has evolved as a distributed ledger technology that enables participant-to-participant exchanges without the need for a central market body. This work solves this issue by demonstrating the laboratory-scale deployment of a blockchain network for the exchange of solar energy between members using Hyperledger, an open-source collaborative effort. The participants, assets, and transactions required to construct the blockchain-based network for tracking solar PV output exchanges, as well as the smart contract, use cases, and their implementation, are explained.

The authors of Reference [95] presented a decentralised market mechanism based on a private blockchain and a price-determination auction process. However, it is conceptually impossible for all users to trade surplus energy via auction or bidding [97]. The reason for this is that some consumers or prosumers are unable to participate in trading due to a lack of time, expertise, or, most importantly, technology. Similarly, another issue was raised in References [95, 97], and a single point of failure is a possibility, as the proposed models permitted a third party to operate as a controller, managing or controlling prosumers' batteries and all transaction information. Additionally, the system is vulnerable to privacy hazards, such as data exposure and security concerns. Additionally, incorporating a third party necessitates the establishment of a central processing centre to handle and collect data from all participants, which is difficult in DER. When relying on a third party, two issues inevitably occur. To begin, a central controller requires extensive communication infrastructure. Second, it is difficult to attract a large number of energy trading participants. By examining the HEM system and demurrage mechanism in a neighbourhood with household photovoltaic energy generation, we suggest an LEM based on a private blockchain. Prosumers and consumers can manage their resources and information in a decentralised, safe, trustworthy, transparent, anonymous, and verifiable manner using the proposed model.

Based on the topic “Designing and Implementing Blockchain-based Platform for Exchange of Peer-to-Peer Energy Trading. Architectural Modelling of P2P energy integration", there are several potential research gaps that can be addressed.

Several research gaps and opportunities are identified based on an assessment of the available literature.

### 2.4.1 Technical Challenge

Decentralised blockchain platforms face technological issues in scaling, interoperability, and energy data management. Improved consensus methods, faster transaction processing, and tighter interaction with existing energy infrastructure are all areas that need further attention in the future.

### 2.4.2 Structures of Law and Regulation

More research is needed into the legal and regulatory implications of decentralised energy trading systems. More study is needed to build regulatory frameworks that safeguard consumers, provide equitable pricing, and maintain reliable grid operations without stifling innovation.

Insufficient research has been done to determine whether or not blockchain-based energy trading platforms can be profitable. Decentralised P2P energy trading may provide significant savings, revenue, and business model opportunities that need to be explored in the future.

### 2.4.3 Consumerism and the Dynamics of Social Acceptance

In the context of distributed energy resources, there is a dearth of research on public opinion and individual behaviour. The social impact, trust-building mechanisms, and consumer adoption rates of P2P energy trading should all be investigated.

### 2.4.4 Evaluation of Effects on the Environment

More research is needed to fully understand the environmental effects of decentralised energy systems. Life cycle emissions, energy efficiency, and overall environmental sustainability of blockchain-based energy trading platforms should be evaluated in future research.

As can be observed, practically all previous blockchain-related work has concentrated on market and business concerns and has omitted technical implementation details. We proposed a blockchain-based P2P trading by considering the use of a Smart Contract Automation strategy in the local community with PV and EV energy trading among participants and trading excess energy to the Grid. The proposed model allows Prosumers to manage their energy resources and information in a P2P platform in a transparent, secured and verified manner.

The research aim of this study is to design and implement a P2P energy trading platform that uses blockchain technology. The platform will allow home owners with solar PV, energy assets, electric vehicles (EVs), and micro grids to trade electricity with each other. The platform will be built on the Ethereum blockchain framework.

The focus is to provide the technical implementation of how the Ethereum blockchain p2p trading platform exchanges energy. Contribution

- A system architecture for the P2P blockchain trading platform

- Proposed a blockchain-based P2P energy trading platform intended to facilitate the exchange of excess solar PV, Grids and EV output in a community.

In conclusion, this examination of the literature has shown major flaws in our understanding of a novel approach to clean energy that integrates blockchain technology, renewable power sources, and localised power grids for P2P energy trading. These knowledge gaps must be filled in order to overcome technical, legislation, economic, and social barriers to an energy future that is both sustainable and efficient. Implementation and execution of these ideas on a worldwide scale require cooperation between researchers, governments, industrial players, and communities.

## 2.5 Summary

Chapter Two provides the context and background required to comprehend the complexities of blockchain-based P2P energy trading in the UK's electricity market. This chapter examines the complexities of the UK electricity market, examines fundamental energy trading concepts, and introduces the Microgrid Energy Market as a theoretical framework for our study. Renewable energy sources, the United Kingdom's transition to renewables, escalating energy costs, and the examination of transformative technologies such as V2G technology are covered in this article. The chapter concludes by identifying research voids that pave the way for our study's original contributions.

Important Points in Chapter Two:

Contextualising the UK Electricity Market: We commence by gaining an understanding of the market's dynamics. This includes a thorough analysis of its structure, stakeholders, regulatory frameworks, and obstacles, laying the foundation for understanding the need for innovative solutions such as blockchain-based P2P energy trading.

Energy Trading Concepts: This chapter explores the fundamental concepts of energy trading, including supply and demand, grid dynamics, and the function of intermediaries. These concepts serve as the foundation for our examination of peer-to-peer energy trading.

The concept of the Microgrid Energy Market, which functions as the theoretical foundation for our research, is introduced. This section examines the complexities of microgrids, their capacity for integrating renewable energy sources, and their role in improving energy resilience and efficiency.

Transition to Renewable Energy Sources: Renewable energy sources and the United Kingdom's endeavours to increase their share of the energy mix receive considerable attention. We investigate the challenges and opportunities posed by renewables, as well as their effect on the energy landscape.

Escalating Energy Costs: This chapter addresses the pressing issue of escalating energy costs, which has sparked interest in alternative energy trading models. We examine the factors that contribute to rising costs and the potential for P2P trading to mitigate these obstacles.

Vehicle-to-Grid (V2G) Technology: An examination of transformative technologies includes V2G technology, which has the potential to revolutionise the generation, storage, and distribution of energy. We investigate the V2G principles and their implications for energy trading.

Feed-in-Tariff (FIT): The chapter discusses FIT, an incentive mechanism for renewable energy generation. We evaluate its role in advancing the use of renewable energy technologies in the United Kingdom.

In conclusion, Chapter Two not only establishes the context for our research but also provides the essential context and theoretical framework necessary to comprehend the complexities of blockchain-based P2P energy trading. Our investigation is grounded in the realities of the UK Electricity market, energy trading concepts, and the changing dynamics of renewable energy adoption and rising energy costs. This chapter prepares the reader for a more in-depth examination of the implementation of blockchain technology in addressing these challenges and opportunities in subsequent chapters.

Table 2 Comparative analysis of the current survey with existing studies

| Study | Objectives | Research Achievements | Type of Blockchain | Status | Limitations |
|---|---|---|---|---|---|
| **Yahaya et al. (2020)** | Blockchain-based sustainability local energy trading(LEM) and demurrage mechanism | To maximize energy supplier and economic benefit | Public blockchain | Case study | Penalty policy<br>Regulation issues<br>Scalability issue |
| **Pipattanasomporn et al (2018)** | A Blockchain-based platform for the exchange of solar energy | Technical implementation for the exchange of energy | Public blockchain-Hyperledger | Proof of Concept (Lab-based) | Electricity cost is not consider<br>Security and privacy |
| **Worner et al. (2019)** | Trading solar energy within the neighbourhood: Field implementation of a blockchain-based electricity market | Provide a systematic literature review of the existing academic articles and industry projects. | Public Blockchain | Simulation | Profit maximization and energy cost is not considered<br>Technical system design<br>Security and privacy |

| | | | | | |
|---|---|---|---|---|---|
| **Noor et al. (2018)** | Energy Demand Side Management within micro-grid networks enhanced by blockchain. | Reduce the Peak-to-Average ratio to benefit the electrical grid | Public Blockchain/ Game based algorism | Case study | Load shedding event<br><br>Hybrid renewable energy<br><br>Stable grid operation |
| **Wang et al. (2017)** | A Novel Electricity Transaction Mode of MicrogridsBased on Blockchain and Continuous Double Auction | Feasibility of market mechanism and improvement of the energy market | Public Blockchain | Case study | There is less flexibility in the CDA bidding process. |
| **Mengelkamp et al. (2017)** | To implement a local LEMP and optimize renewable energy | To measure the market development and participant in LEM | Private blockchain / Scheduling algorithms | Agent-based simulation | Security and privacy |
| **Saxena et al 2021** | Blockchain-based Residential Energy trading system (RETS) | To reduce the peak demand for DERs | Permission blockchain system | Real-world case study. | V2G contracts not considered<br><br>Scalability issue |

### 2.5.1 Comparison Table of Related work with Proposed work

Table 3 Comparison Table of Related work with Proposed work

| Article(Author) | Year | P2P Blockchain Implementation | Transactive Energy System | Bidding Strategies | Blockchain Characteristics/ Types | Real-world Deployment | EV Evolution | HOMER Optimizer | EV/V2G Types/Token Incentives |
|---|---|---|---|---|---|---|---|---|---|
| **Zhang et al.** | 2017 | X | ✓ | x | X | ✓ | X | x | X |
| **Pipattanasomporn et al** | 2018 | ✓ | x | ✓ | ✓ | ✓ | x | x | x |
| **Noor et al** | 2018 | x | X | X | ✓ | ✓ | ✓ | x | X |
| **Andoni et al** | 2018 | x | ✓ | ✓ | ✓ | ✓ | X | xx | X |
| **El-Ashmawi et al.** | 2020 | X | X | ✓ | X | X | ✓ | x | X |
| **Sarralde et al** | 2014 | ✓ | X | | X | ✓ | ✓ | x | X |
| **Dalquist et al.** | 2017 | ✓ | ✓ | X | ✓ | ✓ | X | x | X |
| **Mussadig et al** | 2022 | x | x | | x | x | x | ✓ | x |
| **Saxena et al.** | 2021 | ✓ | ✓ | ✓ | X | ✓ | | x | X |
| **Our Proposed Research** | 2023 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

# CHAPTER 3 Blockchain technology

## 3.1 Introduction

The digital domain has experienced a significant transformation, instigated by the revolutionary influence of blockchain technology. The aforementioned disruptive force has attracted widespread global attention, captivating inventors and organisations alike. The decentralised and immutable nature of this phenomenon, in conjunction with its capacity to revolutionise numerous sectors, has engendered a pervasive sense of fascination. As the evolutionary trajectory of blockchain technology progresses and reaches a state of maturation, it not only serves as a testament to the remarkable capacity for innovation within the technological realm, but also holds the potential to fundamentally reconfigure the manner in which we interact with data and execute transactions within the digital period.

This chapter aims to delve into the fundamental features of Ethereum decentralise P2P energy trading systems, demonstrating the foundational role played by blockchain technology in facilitating the transformative capabilities of these decentralised energy ecosystems.

### 3.1.1 Definition

Blockchain technology's primary aim was to record the transaction in a shared ledger within the community network [98]. The concept of blockchains was combined with other technologies to create a modern cryptocurrency in the year 2008. This blockchain technology gains awareness and acceptance with the launch of Bitcoin in the year 2009. Blockchains are the foundation of cryptocurrency and a simplified payment verification process. Blockchain technology will mature in several areas as the research in this field grows. A blockchain is a decentralized, shared and distributed data structure. In other words, the data structure is a ledger. This could include digital transactions, data logs and executables [39]. It is a new model of networking such as distributed data storage, consensus mechanisms and encryption algorithms.

According to [21], Blockchain is a technology specialist to Peer-to-peer trading platforms. It uses decentralized storage to record all the data on the transaction. In a decentralized system, the computer is connected to nodes with the same power in the network and no centralized server. A node is defined as an individual user in a decentralized system. Nodes can send and receive a message from each connected member.

## 3.2 Decentralization P2P Energy Exchange Platforms

Beyond its broad effects on businesses, blockchain technology has created new paradigms, such as decentralised peer-to-peer energy trading platforms, which are a prime example of its disruptive power. These systems are revolutionising the energy industry by emulating the three fundamental characteristics of blockchain: decentralisation, transparency, and security.

### 3.2.1 Energy Trading Decentralisation

By utilising blockchain's decentralised design, decentralised peer-to-peer energy trading does away with the necessity for centralised middlemen. Direct transactional interaction amongst grid participants promotes a more resilient and democratic energy infrastructure. Eliminating middlemen not only improves efficiency but also fosters inclusivity by allowing people and companies to engage in the energy market.

### 3.2.2 Transparency and Traceabilty

Because of blockchain's transparency, every energy transaction is documented and accessible to all network users. In addition to increasing participant trust, this transparency offers an extensive, unchangeable record of energy transfers. By tracing the energy's origin, participants can ensure accountability and help create a more transparent and accountable energy market.

### 3.2.3 Immutabilty and Security

The integrity of energy transactions is strengthened by the security aspects of blockchain, which include consensus methods and cryptographic procedures. Energy trades are virtually impossible to tamper with once they are recorded on the blockchain. Because of its immutability, which guarantees transaction legitimacy and reduces fraud risk, the P2P energy trading system is seen as dependable.

### 3.2.4 Automated Transactions using Smart Contracts

Blockchain technology's signature feature, smart contracts, are essential to automating and enforcing the terms of energy transfers. These self-executing contracts ensure that energy trades happen automatically when predetermined conditions are met by enabling smooth, code-driven agreement execution. The trading process is streamlined by this automation, which also lessens the need for manual intervention.

### 3.2.5 Integration of Resilient Microgrids

The emergence of microgrids—localized energy networks that can function separately or in tandem with the main power grid—is facilitated by decentralised peer-to-peer energy trading. The resilience of the entire energy system is improved by this microgrid integration, especially during times of high demand or outages.

## 3.4 Overcoming Difficulties in Peer-to-peer Energy Trading

Peer-to-peer (P2P) energy trading systems are evolving and present opportunities as well as obstacles. To fully realise the potential of blockchain technology in transforming the energy sector, these obstacles must be overcome.

### 3.4.1 Solutions for Scalability

When decentralised P2P energy trading systems grow, scalability of blockchain networks becomes an increasingly important concern. In order to handle more transactions efficiently without sacrificing network integrity, research and development efforts are being made to investigate novel methods, such as layer-two scaling techniques.

#### Adapting Regulations

Integrating decentralised energy trading successfully requires navigating regulatory environments. Maintaining compliance with current standards while promoting innovation is still a difficult issue to accomplish. Establishing frameworks that facilitate a smooth transition to decentralised P2P energy trading requires cooperation between regulators and industry parties.

#### Energy Token Standardisation

Establishing universal standards for energy tokens is necessary for the energy industry to support interoperability and widespread adoption. This standardisation makes it easier to trade and transfer energy assets on blockchain networks and guarantees consistency across various platforms.

#### Improving the User Experience

To promote wider involvement, blockchain-based energy trading systems' user interfaces and experiences need to be improved. Ensuring a user-friendly experience and streamlining the user's contact with the technology are vital to propel its adoption among industry stakeholders and customers.

Innovation and Prospects for the Future

Future innovations seem promising as decentralised P2P energy trading systems continue to develop. Novel consensus processes, integration with cutting-edge technologies like the Internet of Things (IoT), and improved smart contract capabilities are all being investigated in ongoing research. The objective of these developments is to enhance the effectiveness, safety, and durability of decentralised energy systems.

## 3.2 History of Blockchain

The early concept of the electronic cash model was first proposed in 1980 by David Chaum, a PhD Computer Science from UC Berkeley. He is a lead to Elixxir and Paxxis to provide DigiCash and Voting Systems [99]. Also, the concept of blockchains was presented by Leslie Lamport [100], the Part-time parliament, who submitted a research paper on ACM transactions on a computer system in 1998. That paper presented a consensus model to agree on computer networks. Author [101] noted a system and method to allow electronic cash through a universal computer network, wireless and hardware system. Chum's work on untraceable electronic mail proposed a way for individuals to contact with record-keeping institutions under a pseudonym and appear in a list of permitted clients. [102].

Further, that concept was implemented in an electronic cash system in 2008 under the research title *"Bitcoin: A peer-to-peer Electronic cash system"* by Satoshi Nakamoto [103]. The research on Blockchain was based on the time stamping of packages and for protecting the chain of custody [39]. Many other electronic cash schemes have been presented and implemented before, but Bitcoin was the only one that achieved widespread use and popularity. The development of blockchain-enabled Bitcoin was distributed so that none of the users managed the e-cash, and no single point of failure was possible. The bitcoin enables the users to make the transactions without any trusted third party and permits the users to be pseudonymous but with the transparency of transitions. Bitcoin is the best-known application of blockchain-related to currency transfer, digital payment, and remittance systems [104]. Another famous application of Blockchain is the development of the "Smart Contract" system. A digital protocol that automatically processes the transaction without involving the third party.

The application of blockchains is not only limited to financial services, but it also has a wide range of applications, including the Internet of things (IoT), smart contracts, public services, security services and reputation systems, Supply chain management and energy markets. Bitcoin is the first cryptocurrency born in 2008 to become an alternative to traditional payment methods, and three primary purposes differentiate Bitcoin from traditional currency: Simplify trade, Memorize the value created by users for future goals, Act as a unit to be able to measure the market value of goods and services. It used Public key cryptography with a Proof of Work mechanism to directly provide a secure, decentralized online payment to an individual without the Bank.  The concept of Bitcoin includes other technologies such as Merkel trees, hash function and hash chains [105]. The identity of Satoshi Nakamoto remains anonymous.

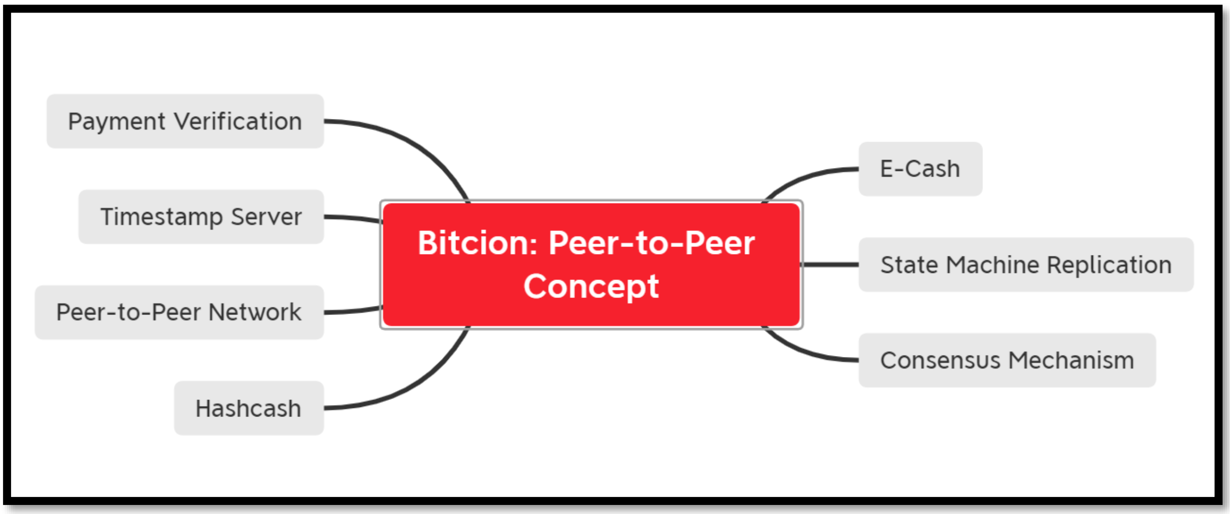



Figure 3. 1 The concept of Bitcoin [105]

Ether (ETH)

As a digital currency specifically created for the Ethereum blockchain, Ether (ETH) represents the idea of a programmable, decentralised financial ecosystem. Acting as the energy source for Ethereum apps' smart contracts and transactions, ether represents the shift to a digital currency that is available everywhere. Ether continues to be a vital component of financial inclusion and innovation in our digitally connected society, even as Ethereum continues to influence the direction of blockchain technology [106].

### 3.2.1 Type of Blockchain Application

Permissionless and public blockchains, such as Ethereum or Bitcoin, are the most popular. They are, in principle, available to everyone if the necessary infrastructure is in place. Typically, participants are anonymous to other participants and are identified just by a random ID as their personal address. In the first instance, there is no central provider tasked with the responsibility of supervising ongoing traffic. For the most part, public blockchains use the so-called Proof-of-Work (PoW) consensus mechanism to validate new data blocks. Miners compete against one another to solve a computational challenge, with the winner updating the database and often receiving a reward in the digital currency in question [107]. Then, for each new block, the process is repeated from the beginning. All participating servers verify the validity of the solved puzzle and the integrity of the entire blockchain. Because the majority of all players supervise the full history of transactions, this advanced consensus method renders trust between individual actors obsolete. The reliability of a public blockchain is highly dependent on the presence of a sufficient number of miners who provide the necessary processing power and storage capacity. Numerous attempts are devoted to developing resource-efficient alternatives to the Proof-of-Work (PoW), such as the Proof-of-Stake (PoS) [108]. If these efforts succeed, public blockchains will have a number of significant advantages over private or consortium blockchains. To begin, it enables the participation of unrelated devices (machines, mobile phones, tablets, that are not required to be trustworthy. Second, no consortium or commercial provider is obligated to accept new blockchain-based apps. These two traits may be critical in a future IoT situation when random devices communicate in near real-time.

Blockchain is divided into three categories based on their stage of development; they are:

- Blockchain 1.0 comprises virtual cryptocurrencies such as Bitcoin.
- Blockchain 2.0 comprises a smart contract representing a digital protocol that automatically executes predefined processes of a transaction without requiring the involvement of a third party.
- Blockchain 3.0 is the further development of smart contracts to create decentralized autonomous organization units that rely on their laws and operate with a high degree of autonomy.

Table 4 Blockchain types: private, public, and consortium [109]

| | Private | Public | Consortium |
|---|---|---|---|
| Access | *Permissioned* | Permissionless | Shared permissioned |
| Consensus Mechanism | PoA, PBFT, | PoS, PoW | PoW, PoA, PoS |
| Personal information | Known | Pseudonymity | Known |
| Security | Single point of failure | Decentralized control | Various |
| Transaction Speed | High | Low | High |
| **System cost** | **Low** | **High** | **Medium Low** |

## 3.3 Ethereum Blockchain Model

It was created in 2013 by Vitalik Buterin, a developer who does not go by the pseudonym Vitalik Buterin. The Ethereum network saw its first public release in 2015. 2017 was a year of surprises. Ethereum Enterprise Alliance is a group of companies trying to develop standards for using Ethereum in commercial applications. Ethereum, like Bitcoin, is a cryptocurrency. Its symbol is three parallel lines, and it is called Ether or ETH. It also allows financial transactions, just like Bitcoin [110].

Blockchains are transaction databases maintained and shared across network machines. Each fresh set of transactions is called a "block"—hence blockchain. Public blockchains like Ethereum allow data addition but not deletion. Someone would need to hack most network computers to change data or deceive the system [110].

Figure 3. 2 Ethereum transactions send currency or information on the network. Ethereum, a decentralised blockchain technology, allows smart contracts, self-executing contracts with coded stipulations, to be created and executed. Ethereum transactions involve smart contracts and Ether (ETH), the platform's money.

Key Ethereum transaction details:

The simplest basic Ethereum transaction is transmitting Ether (ETH) between addresses. This is like regular financial transactions on a decentralised blockchain.

Ethereum transactions can also execute smart contracts. Smart contracts run on the Ethereum Virtual Machine (EVM) and can transfer tokens, manage agreements, or execute complicated logic.

Gas: Ethereum senders pay "gas" for transactions. Gas measures the computing effort needed to run smart contracts or processes. Gas costs rise with transaction or smart contract complexity.

The transaction hash, a long string of letters, is a cryptographic fingerprint for each Ethereum transaction. This hash tracks and verifies blockchain transactions.

Confirmation: Ethereum miners approve and include transactions in blocks. More confirmations make a transaction more secure and irrevocable.

Decentralisation: Ethereum records and validates transactions on a decentralised network of computers. The network is decentralised, so no one controls it.Ethereum transactions enable users to transfer wealth, execute smart contracts, and engage in Ethereum-based DApps.

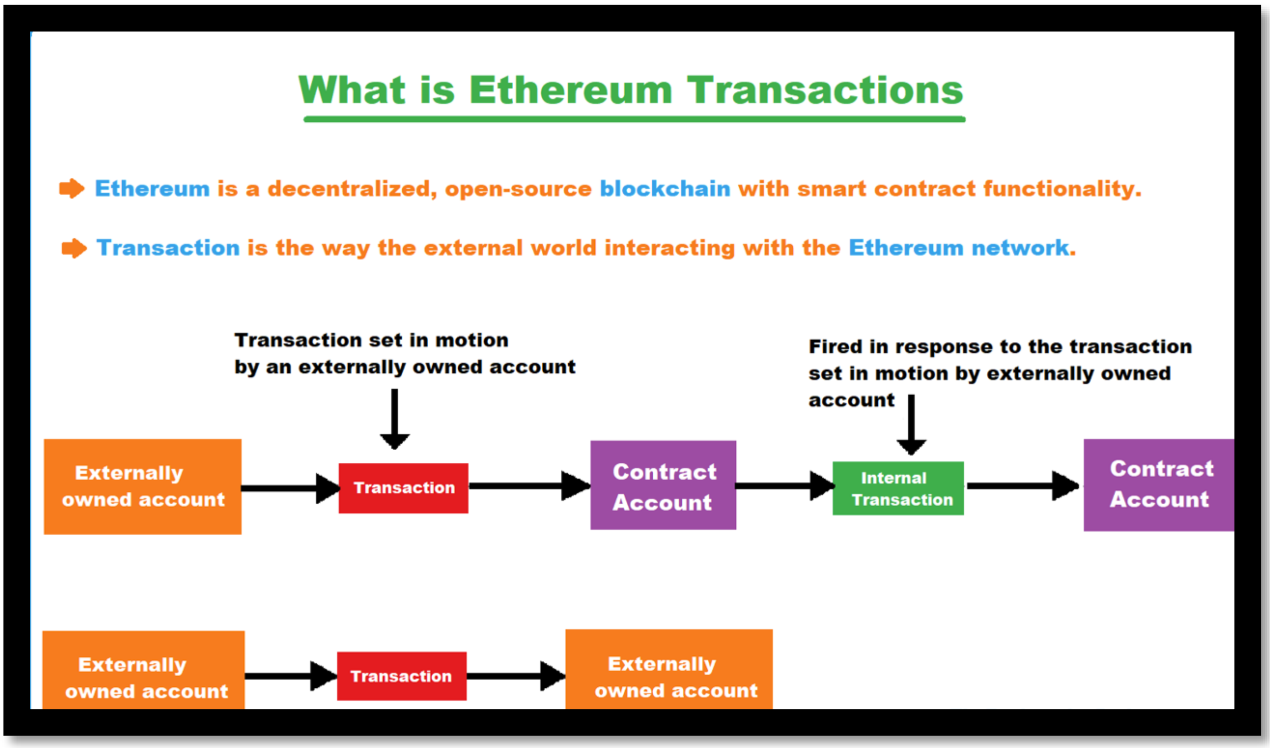



Figure 3. 2 Ethereum Transactions [111]

## 3.4 Ethereum's origins

Ethereum is a ground-breaking development in blockchain technology that was conceptualised by Vitalik Buterin and presented in his foundational article [112]. It was designed to expand the possibilities of decentralised apps and smart contracts in response to perceived restrictions in the scripting language of Bitcoin.

Relevant Contributions

When Ethereum was introduced, it changed the game by fixing a number of issues with Bitcoin, including:

Complete Turing Completion

The addition of full Turing completeness to the programming language is one of Ethereum's primary accomplishments. Ethereum provides for the execution of a wide range of computations, including loops, in contrast to Bitcoin's restricted scripting language. This improvement makes it possible to use a wider range of decentralised apps and computational features.

Contextualised Exchanges

Ethereum introduces the idea of state in transactions, which elevates it above Bitcoin's basic transaction paradigm. Value is transferred as the main purpose of transactions in Bitcoin. Conversely, Ethereum has a more sophisticated state architecture that enables more intricate and flexible transactions.

Improvements to the Structure of Blockchain

Apart from introducing stateful transactions and Turing completeness, Ethereum enhances the traditional blockchain architecture in multiple structural ways. These improvements add to the overall resilience, scalability, and efficiency of the platform.

Ethereum's Core: Smart Contracts

Smart contracts are the foundation of Ethereum's transformational power. These consist of programmable scripts and sets of cryptographic rules that only run when particular predetermined criteria are satisfied. Smart contracts offer an abstract layer that expands the customisation options available on the Ethereum blockchain by allowing users to specify their own guidelines for ownership, transaction forms, and state transition procedures [112].

Strengthening Distributed Innovation

A new era of decentralised innovation is fostered by Ethereum's integration of smart contracts and embracing of full Turing completeness. With it, developers, companies, and people may design and implement own decentralised applications (DApps) with a degree of programmability and flexibility not found in blockchain technology before.

Ongoing Evolution

Upgrades like Ethereum 2.0 are attempts to improve sustainability, scalability, and security as the platform develops. These enhancements highlight Ethereum's resolve to overcome obstacles and strengthen its standing as the industry's top platform for smart contracts and decentralised applications [110].

The Ethereum network relies on a modified version of the GHOST protocol, which stands for Greedy Heaviest Observed Subtree [113]. It was developed to address the network's stale block problem. Stale blocks can happen when a mining pool's aggregate processing power is greater than that of the other groups of miners. This means that the blocks from the first pool will contribute more to the network, which will lead to a centralization problem. These outdated blocks are taken into account by the GHOST protocol for determining the longest chain.

Currently, Ethereum's goal is to combine and improve upon the concepts of scripting, altcoins, and on-chain meta-protocols, enabling developers to create arbitrary consensus-based applications that benefit from the scalability, standardisation, feature completeness, ease of development, and interoperability provided by these disparate paradigms. Ethereum accomplishes this by establishing what is essentially the ultimate abstract foundational layer: a blockchain with an integrated Turing-complete programming language that enables anyone to write smart contracts and decentralised applications with their own arbitrary ownership rules, transaction formats, and state transition functions. A minimal implementation of Name coin can be constructed in two lines of code, while other protocols like as currencies and reputation systems can be built in less than twenty. Smart contracts, which are cryptographic "boxes" that contain value and can be unlocked only when certain conditions are met, can also be built on top of our platform, providing significantly more power than Bitcoin scripting due to the added capabilities of Turing-completeness, value awareness, blockchain awareness, and state[110] .

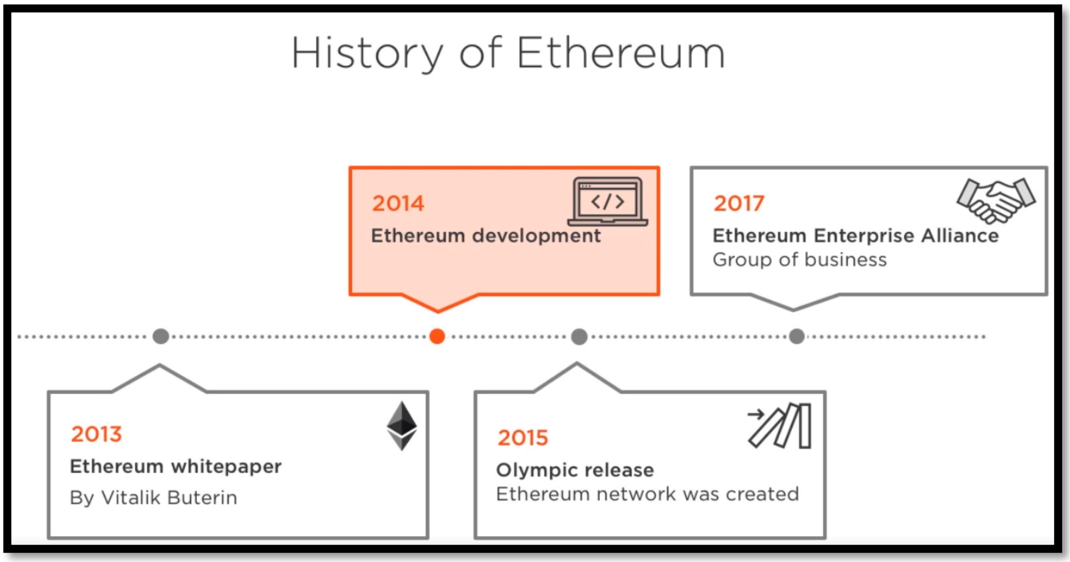



Figure 3. 3 History of Ethereum [114]

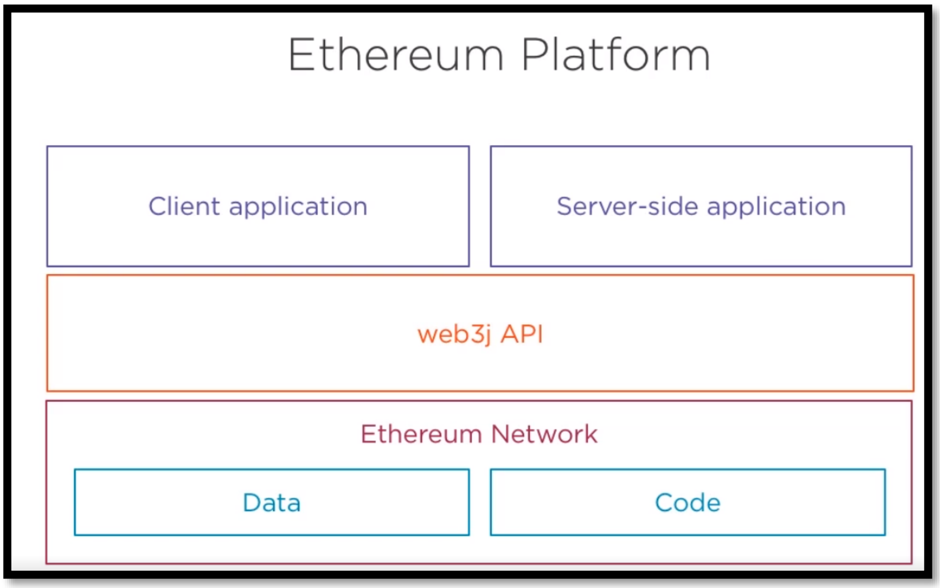



Figure 3. 4 Ethereum Platform [114]

### 3.4.1 Ethereum Accounts: Foundation of Ethereum State

In Ethereum, the state is made up of objects called "accounts", with each account having a 20-byte address and state transitions being direct transfers of value and information between accounts [115]. An Ethereum account contains four fields [113, 115, 116]:

- The nonce, a counter used to make sure each transaction can only be processed once
- The account's current ether balance
- The account's contract code, if present
- The account's storage (empty by default)

### 3.4.2 Addressing the Ethereum Network

Every Ethereum account has a unique 20-byte address that acts as an identification on the network. These addresses are produced by cryptographic procedures that allow for exact locating and communication with particular Ethereum blockchain accounts.Ethereum State's Components:All accounts and their associated balances are essentially listed in the Ethereum state. It includes the following essential elements:

Ether Balances The quantity of Ether (ETH), the native coin, linked to a certain Ethereum account is shown by its Ether balance.

Nonce: A nonce is a special number that is linked to every transaction that comes from a certain account. In addition to guarding against replay attacks and guaranteeing that each transaction is handled just once, it guarantees the chronological sequence and integrity of transactions.

Storage and Contract Code: Ethereum supports contract accounts as well as externally owned accounts (EOAs). These accounts have storage and contract code, which allows sophisticated and programmable smart contracts to run on the Ethereum Virtual Machine (EVM).

Changes in States: In Ethereum, "state transitions" are the modifications made to the system's state as a result of transactions and smart contract execution. The Ethereum network processes each transaction that is started, which might result in changes to nonces, storage, contract code, and account balances.

There are two main kinds of Ethereum accounts [110]:

Contract Accounts and External Owned Accounts (EOAs)

1. Accounts owned by third parties (EOAs):Private keys are used to own and manage EOAs. For simple transactions like sending and receiving ether, they serve as user-controlled accounts.
2. And the second Accounts Contractual:Contract accounts are those that have a smart contract code linked to them. These are programmable objects that, in response to a transaction, are capable of executing code. The Ethereum network is decentralised and self-executing in part because of contract accounts.

Ethereum accounts are the foundation of the Ethereum state since they operate as distinct identifiers for users and smart contracts on the network. Both contract accounts and externally owned accounts are essential for enabling state transitions through transactions and smart contract execution. This decentralised design emphasises the openness and integrity of the Ethereum blockchain, especially when combined with immutable historical data.

## 3.5 Ethereum Currency -ETHER(ETH)

As a digital currency specifically created for the Ethereum blockchain, Ether (ETH) represents the idea of a programmable, decentralised financial ecosystem. Acting as the energy source for Ethereum apps' smart contracts and transactions, ether represents the shift to a digital currency that is available everywhere. Ether continues to be a vital component of financial inclusion and innovation in our digitally connected society, even as Ethereum continues to influence the direction of blockchain technology [110]. In his original Ethereum vision, Vitalik Buterin [112] envisaged Ether as more than just a cryptocurrency; rather, he saw it as an essential part of what made the Ethereum blockchain decentralised, programmable, and self-executing. Beyond just serving as a medium of commerce, ether also represents the system of financial incentives that propels participation, innovation, and security throughout the Ethereum network. Ether is a decentralised, international money that is not limited by geography. It acts as a worldwide medium of trade, allowing users to engage in the Ethereum ecosystem without being restricted by the limitations of conventional financial systems. Because of its universality, Ether is positioned as a money for the digital era, representing the increasingly international nature of contemporary trade.

## 3.6 Ethereum Wallets: Your Digital Key to Asset control

Since Ethereum wallets give consumers a safe and convenient way to interact with their digital assets on the Ethereum network, they are essential to the decentralised world of blockchain technology [116]. An Ethereum wallet is a digital tool that works similarly to a physical wallet in that it lets users interact with different Ethereum blockchain applications, manage and control their assets, and authenticate themselves [117].

Ethereum Wallets' Fundamental Purposes

Ethereum wallets are feature-rich programmes made to provide users command over their Ethereum balances. Typically, these wallets provide the following essential features:

Managing Assets

For the most part, Ether (ETH) and other Ethereum-based coins are stored digitally in your Ethereum wallet. It lets you keep an eye on your digital wealth in real time by giving you a consolidated view of all of your holdings and transactions [110].

Confirmation of Identity

Your Ethereum wallet authenticates your identity on the blockchain, much like your physical wallet does with identification cards. Cryptographic keys are used to do this: a private key is used to authorise transactions, while a public key is used to receive assets. Identity verification is secure and impenetrable thanks to this dual-key mechanism.

Managing Transactions

Users can start and approve transactions on the Ethereum blockchain with Ethereum wallets. Your wallet is the entry point to all blockchain-related operations, like as transferring Ether to other users, engaging with DApps, and carrying out smart contracts.

Using Applications

The secret to opening a wide range of decentralised apps created on the Ethereum network is your wallet. The wallet serves as the authentication mechanism for a variety of applications, including blockchain-based games and decentralised finance (DeFi) protocols, enabling you to log in and use them safely.

Ethereum Wallet Types

Ethereum wallets are available in a variety of styles to accommodate varying user tastes and security needs. Among the primary kinds are: Software Wallets Applications installed on desktops or mobile phones are known as software wallets. They can also be divided into two categories: cold wallets, which are offline for increased security, and hot wallets, which are online.

Hard Copy Money: Hardware wallets are tangible objects made especially for offline crypto key storage. By putting private keys out of the reach of possible cyber threats, they offer an extra degree of security.

Banknotes: Using a paper wallet entails writing down or printing your public and private keys on paper. Although this is regarded as a type of cold storage, care must be taken to avoid loss or physical harm. Security Points to Remember:Maintaining security is crucial while working with Ethereum wallets. Because it allows you to access your digital assets, protecting your private key is essential. Users need to be cautious and follow recommended procedures, such turning on two-factor authentication and frequently backing up their wallet data.

Ethereum wallets are the virtual equivalents of physical wallets, giving users the means to traverse the decentralised terrain of blockchain technology. These wallets enable users to interact with the Ethereum network safely and easily by providing secure asset management, identity verification, transaction processing, and application access. Adopting strong security protocols and selecting the appropriate wallet type guarantee a safe and happy journey into the world of blockchain apps and decentralised finance.

## 3.7 ERC-20 Tokens: Standardizing token implementation on Ethereum

The ERC-20 token standard is an indispensable component of Ethereum's tokenization capabilities. Through the establishment of a standardised framework encompassing rules and interfaces, the Ethereum Request for Comments 20 (ERC-20) protocol effectively facilitates the seamless generation, transfer, and engagement of tokens within the Ethereum blockchain ecosystem. The process of standardisation has assumed a crucial and pivotal role in facilitating the widespread adoption and proliferation of token-based initiatives [118]. This standardisation has effectively empowered a wide array of assets and utilities to be accurately represented and seamlessly transacted upon the Ethereum platform. This covers a wide variety of assets, spanning from utility tokens that grant access to certain services to security tokens that reflect ownership in tangible assets [119]. Smart contracts and programmability refer to the ability of computer programmes to automatically execute and enforce agreements or contracts without the need for intermediaries or human intervention.

Smart Contract and Programmability: ERC-20 tokens utilise the capabilities of smart contracts on the Ethereum network. These tokens has the ability to incorporate programmable logic, allowing for the implementation of intricate functionality, such as automated reward distribution and governance procedures [120].

The Decentralised Finance (DeFi) Revolution: The ERC-20 standard has been essential in the emergence of decentralised financial (DeFi) applications. ERC-20 tokens provide smooth integration with several DeFi protocols, enabling users to engage in lending, borrowing, trading, and earning interest on their assets without the need for conventional financial intermediaries [121].

Initial Coin Offerings (ICOs) and Token Sales: The simplicity of generating and overseeing ERC-20 tokens has acted as a driving force behind the Initial Coin Offering (ICO) phenomena. Several projects opt to generate capital by issuing their own ERC-20 tokens, enabling investors to engage in the project and potentially reap rewards from its prosperity [122].

## 3.8 Ethereum Transaction and Messages

Ethereum transactions function as the mechanism for carrying out commands on the blockchain. Transactions are essential in the Ethereum ecosystem as they can involve making calls to existing contracts or creating new accounts. They contribute to the dynamic and decentralised nature of the system. Comprehending the constituent elements and consequences of transactions is crucial for those involved in smart contracts and their contribution to the continuous expansion of the Ethereum network [123].

Messages are an important part of interactions within smart contracts in the Ethereum ecosystem. Messages promote communication between accounts, particularly when calling functions within smart contracts, whereas transactions start changes on the blockchain [112, 115, 123].

Transactions and Messages of Two Kinds

The mixed nature of Ethereum transactions extends to messages, which reflect two types of transactions based on their outcomes:

Message Calls: A message call is the execution of a function within an already existing smart contract. These calls are initiated by users broadcasting transactions to the network, instructing the Ethereum Virtual Machine (EVM) to do specified operations within the targeted contract. Message calls are required for decentralised applications (DApps) and smart contract functioning in general.

Internal Communications: Internal messages, on the other hand, relate to communication that occurs within the execution of a smart contract. Internal messages are generated when a smart contract invokes another contract or generates a new contract during execution. These messages are not initiated by external transactions, but are an inherent part of the logic of the smart contract.

### 3.8.1 Message Components

Messages and transactions share key components, reflecting their role as instructions throughout the Ethereum network:

Addresses of Sender and Recipient

Messages, like transactions, have sender and receiver addresses. The message is initiated by the sender, and the recipient is the account or smart contract that receives and processes it.

**Value**

The value component of a message represents the amount of Ether transmitted with the message. This can be a financial transaction in the context of message calls, or it can be the endowment of Ether to a newly established contract in the context of internal communications.

**Data**

In messages, the data field includes the input parameters and instructions for the smart contract function that is being run. It functions similarly to the data field in transactions, transmitting the information required for the smart contract's execution.

**Message Use Cases**

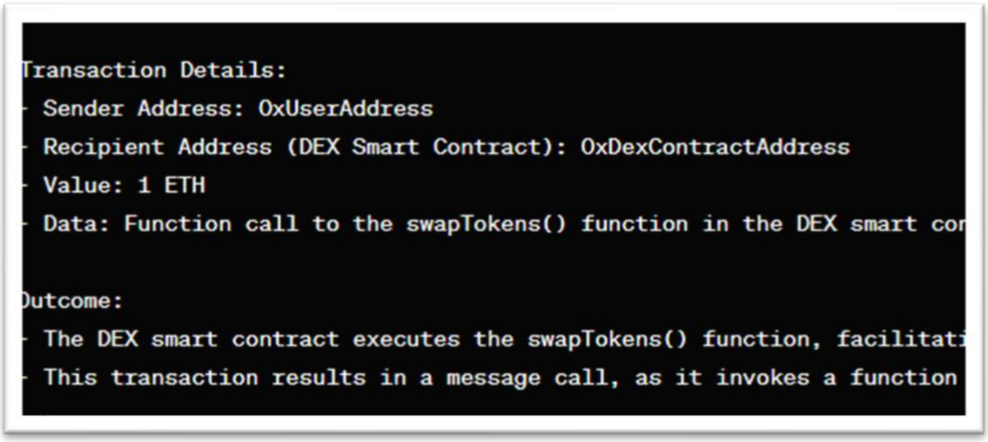
Messages are critical in a variety of use cases within the Ethereum ecosystem: Interaction with Existing Smart Contracts: Message calls allow users to engage with and trigger actions within existing smart contracts, adding to the functionality of decentralised applications.

Contract Creation: When a smart contract generates another contract during its execution, internal messages are generated. This method makes it easier to create complicated decentralised systems and protocols.

Ethereum Logs: Messages and transactions can generate logs as they run. Logs are additional pieces of information emitted by smart contracts that allow them to record events and send data to external apps.

Example of Ethereum Transaction and Messeages

The present research applies to the execution of an Ethereum transaction involving a message call. In the present inquiry, we contemplate a hypothetical situation wherein a user expresses the intention to engage in an interaction with a decentralised exchange (DEX) smart contract, thereby effectuating the exchange of Ether, a prominent cryptocurrency, for an alternative ERC-20 token, which is a class of digital assets adhering to the Ethereum blockchain's token standard.


```
Transaction Details:
- Sender Address: 0xUserAddress
- Recipient Address (DEX Smart Contract): 0xDexContractAddress
- Value: 1 ETH
- Data: Function call to the swapTokens() function in the DEX smart co

Outcome:
- The DEX smart contract executes the swapTokens() function, facilitati
- This transaction results in a message call, as it invokes a function
```

Figure 3. 5 Message use case

Table 5 Ethereum Transaction and Messeages

**Transaction Details**:

- Sender Address: 0xUserAddress

- Recipient Address (DEX Smart Contract): 0xDexContractAddress

- Value: 1 ETH

- Data: Function call to the swapTokens() function in the DEX smart contract, specifying token addresses and amounts.

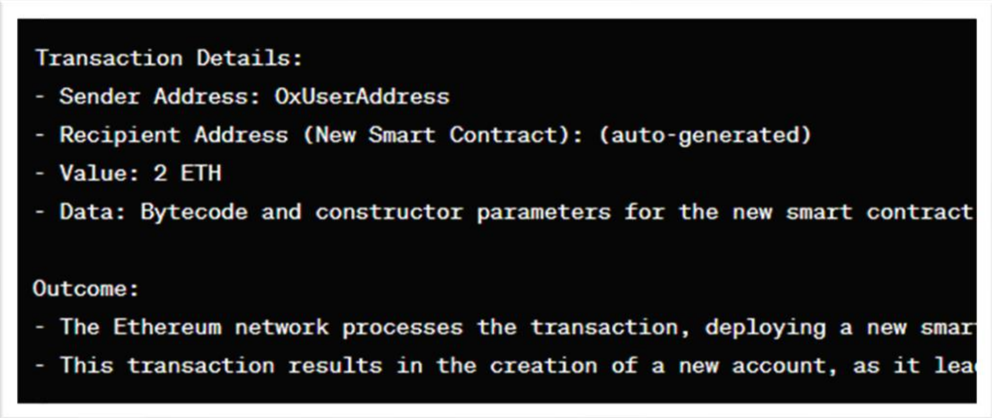
**Outcome:**

- The DEX smart contract executes the swapTokens() function, facilitating the exchange of Ether for the specified ERC-20 token.

- This transaction results in a message call, as it invokes a function within an existing smart contract (the DEX).

Ethereum Transaction Account Registration

Now, let's examine a scenario in which a user initiates a transaction that results in the formation of a novel smart contract.



```
Transaction Details:
- Sender Address: 0xUserAddress
- Recipient Address (New Smart Contract): (auto-generated)
- Value: 2 ETH
- Data: Bytecode and constructor parameters for the new smart contract

Outcome:
- The Ethereum network processes the transaction, deploying a new smar
- This transaction results in the creation of a new account, as it lea
```

Figure 3. 6 Ethereum Transaction Account Registration

Table 6 Transaction Details and outcome

**Transaction Details:**

- Sender Address: 0xUserAddress

- Recipient Address (DEX Smart Contract): 0xDexContractAddress

- Value: 1 ETH

- Data: Function call to the swapTokens() function in the DEX smart contract, specifying token addresses and amounts.

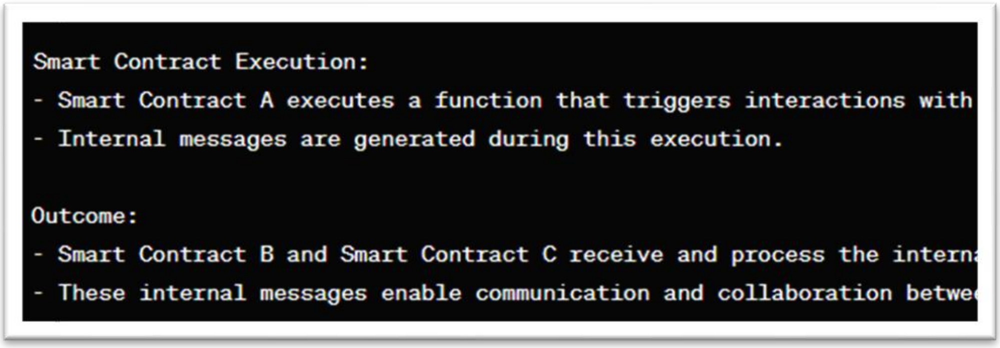
**Outcome:**

- The DEX smart contract executes the swapTokens() function, facilitating the exchange of Ether for the specified ERC-20 token.

- This transaction results in a message call, as it invokes a function within an existing smart contract (the DEX).

Internal communication during the execution of a smart contract

Assume a decentralised application (DApp) incorporates an intricate smart contract that engages with many other contracts throughout its execution.


Smart Contract Execution:
- Smart Contract A executes a function that triggers interactions with
- Internal messages are generated during this execution.

Outcome:
- Smart Contract B and Smart Contract C receive and process the intern
- These internal messages enable communication and collaboration betwe

Figure 3. 7 Execution of a smart contract

Table 7 Smart Contract Execution

| |
|---|
| **Smart Contract Execution:**<br><br>- Smart Contract A executes a function that triggers interactions with Smart Contract B and Smart Contract C.<br><br>- Internal messages are generated during this execution.<br><br>**Outcome:**<br><br>-Smart Contract B and Smart Contract C receive and process the internal messages generated by Smart Contract A.<br><br>-These internal messages enable communication and collaboration between different components of the decentralized application. |

Message Calls: refer to transactions that interact with established smart contracts by activating particular functions and modifying the contract's state.

Account-Creating Transactions: refer to transactions that result in the establishment of new accounts, usually through the utilisation of smart contracts.

Internal Messages: Messages generated and processed within the context of smart contract execution, facilitating communication between multiple contracts.

These examples demonstrate the various ways in which Ethereum transactions and messages enhance the decentralised and programmable characteristics of the Ethereum network. Comprehending these interactions is essential for developers and consumers involved in smart contracts and decentralised applications.

### 3.9 Smart Contract

Smart Contracts are programmes that run in the network in a trustless and tamper-proof manner. It should be noted that Smart Contracts must be deterministic, or else peers may disagree on the outcomes of valid executions. As a result, filesystem and network access, for example, are not permitted. While the term may connote a close relationship with legal contracts, smart contracts have a much broader range of applications and can be used wherever complex conditional logic must be executed automatically. As a result, they can be envisioned as self-executing autonomous agents [124]. Nick Szabo [120] introduced the concept of smart concept and imagined a digital marketplace based on these fully automated, cryptographically safe processes. A site where transactions and commercial processes can take place without the use of middlemen in a secure manner. Ethereum's smart contracts make this vision a reality.

Ethereum applications are built on the foundation of smart contracts. They are blockchain-based computer applications that allow us to convert traditional contracts into digital counterparts. Smart contracts are quite rational, as they follow an if/then pattern. This means they follow the programme exactly and cannot be modified [125].

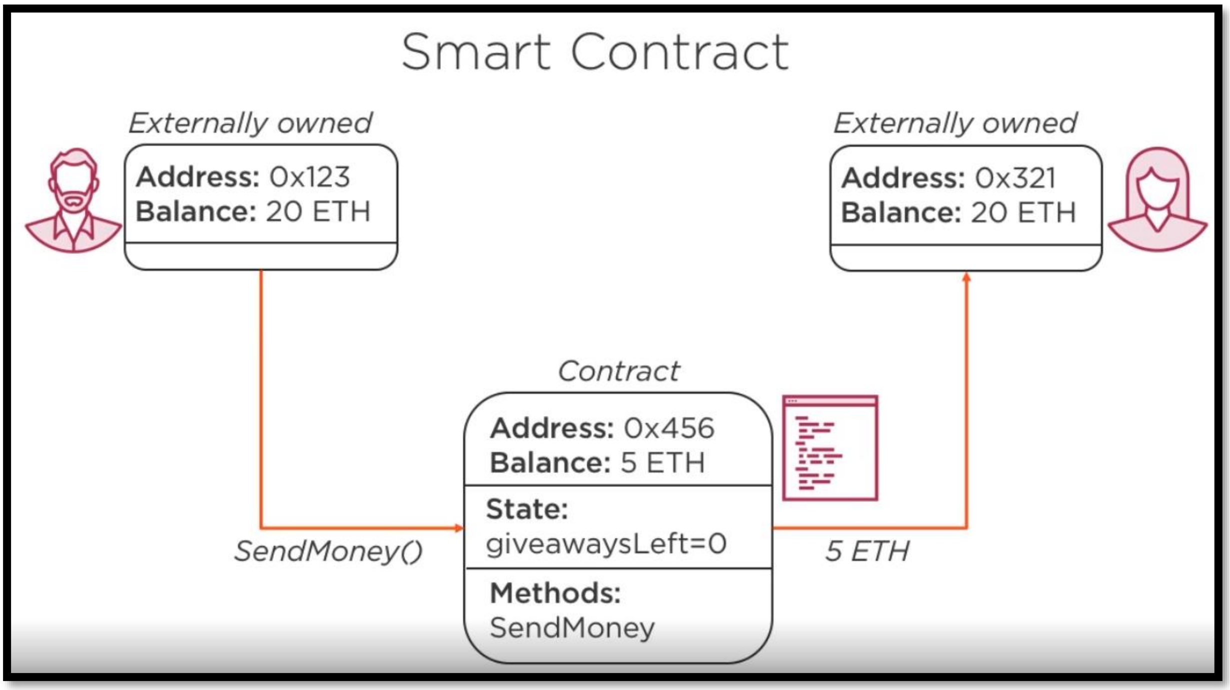



Figure 3. 8 Smart Contract [114]

In the proposed P2P trading platform, the smart contact defines how the trading market is clear into multiple users offers to buy/sell solar generation. The smart contract code is embedded in the Close Bidding transaction. To determine the average bid price offered, this experiment will calculate the market clearing price (MCP). To match selling Offers and buying offers, the study will consider offers to sell excess EV generation that is received first in the bidding process.

### 3.9.1 Solidity Programming Language

The research will use the solidity programming language to develop DApp. Solidity is a smart contract programming language that may be executed by the Ethereum Virtual Machine (EVM). It follows assembly language, web development, and networking conventions. Ethereum smart contracts are written in a high-level language. Smart contracts can be written in a variety of languages, including LLL, Serpent, Viper, and Solidity. Solidity is a Turing-complete, statically typed programming language that supports inheritance, polymorphism, and libraries. Its syntax is similar to that of JavaScript [126].

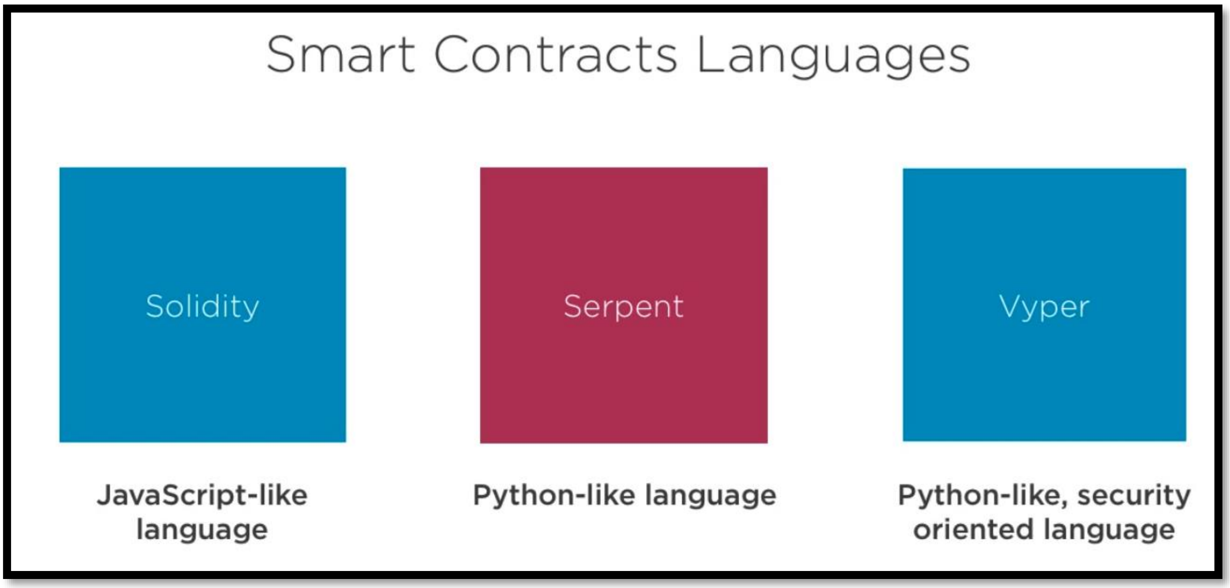



Figure 3. 9 Different smart contract Programming languages [114]

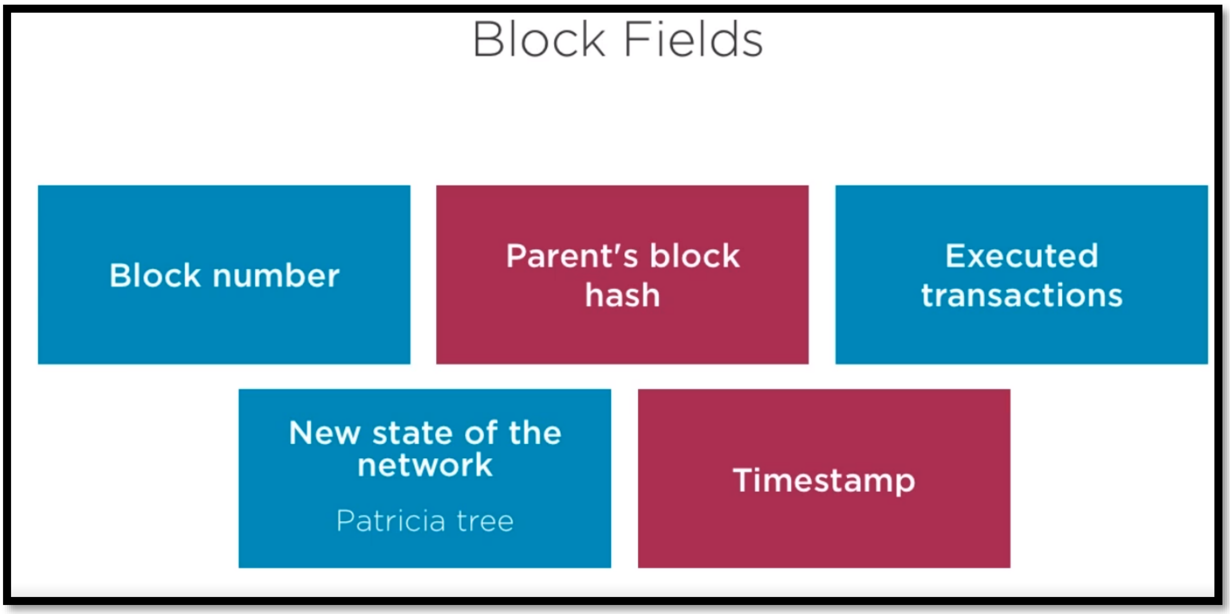



Figure 3. 10 Block Fields [114]

Remix IDE

Ethereum developers frequently utilise Remix IDE, particularly those who are novices in smart contract development or desire a user-friendly environment to construct and test decentralised applications. Because it is an open-source project, it is accessible to developers via web browsers only, eliminating the requirement for supplementary installations. Figure 3. 11 using MetaMask streamlines the administration of Ethereum assets and facilitates communication on the decentralised web. Users of DApps, DeFi platforms, and other blockchain applications have embraced it as a tool that has attained widespread adoption within the Ethereum ecosystem.

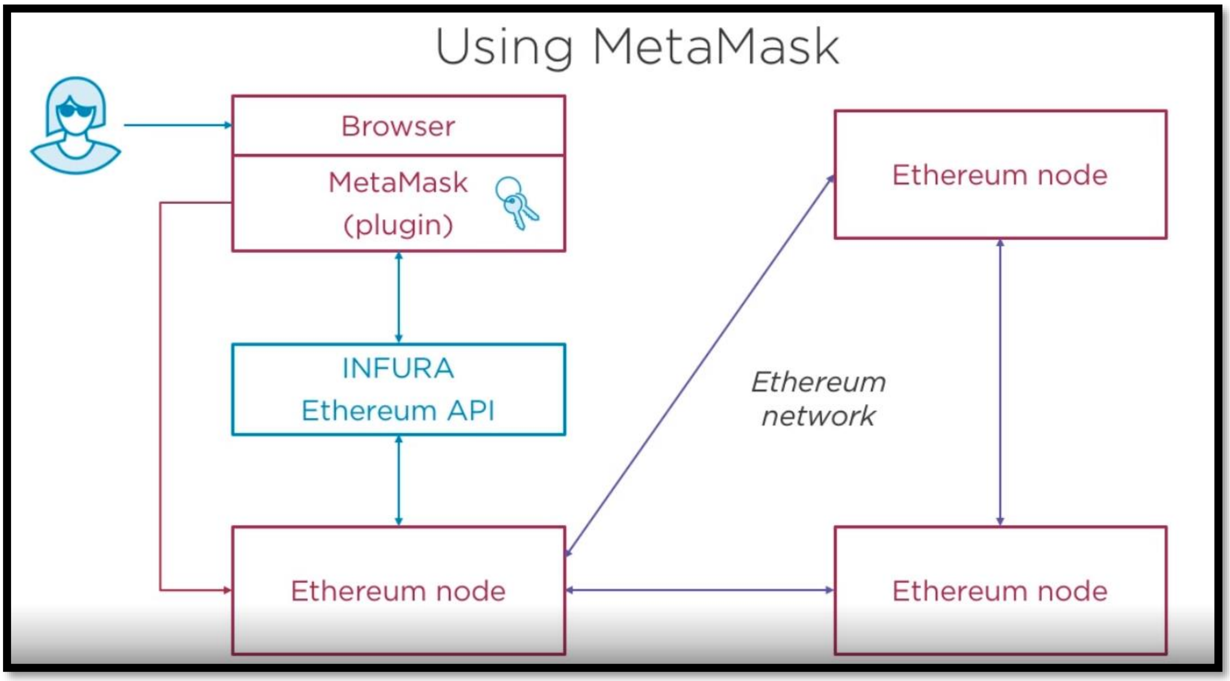



Figure 3. 11 Using MetaMask [114]

### 3.9.2 Truffle Framework

This is a development environment, testing framework and asset pipeline for blockchain using the Ethereum Virtual Machine (EVM).

In Fig. 3.12 Truffle framework: Truffle simplifies Ethereum project development with a developer-friendly environment. Its ease of use, vast feature set, and active community support make it popular among Ethereum developers. The open-source Truffle framework's documentation gives thorough instructions for Ethereum development.

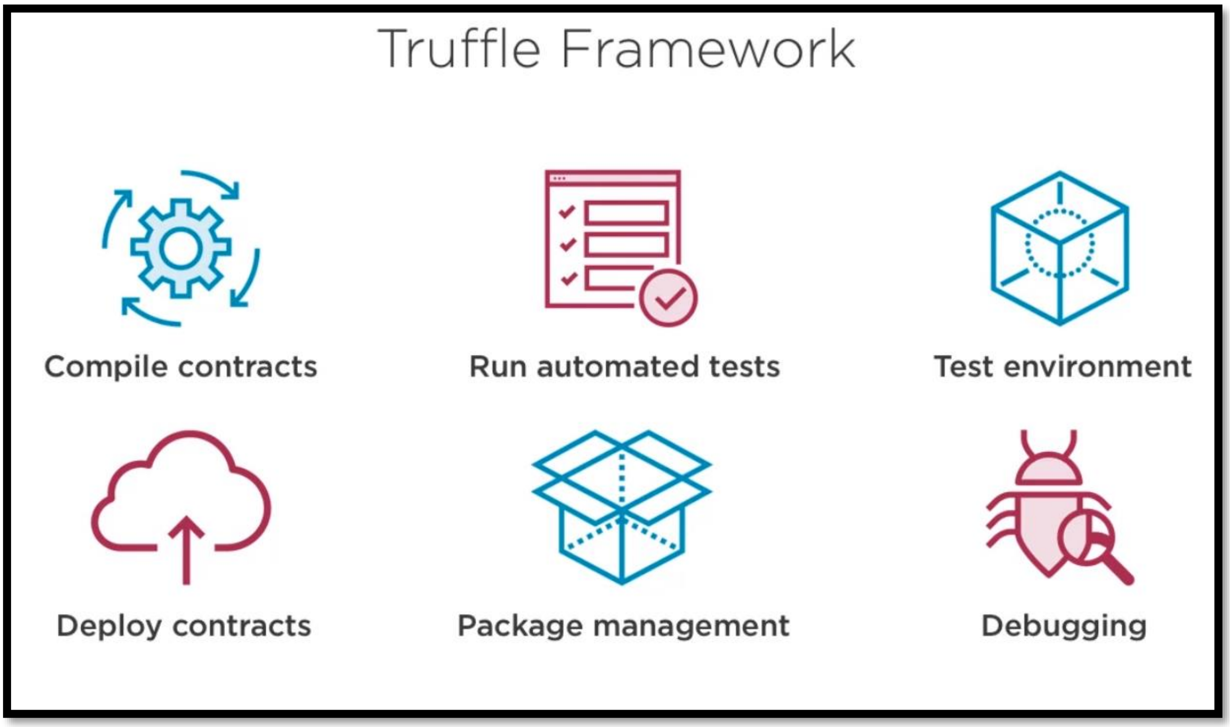



Figure 3. 12 Truffle Framework [114]

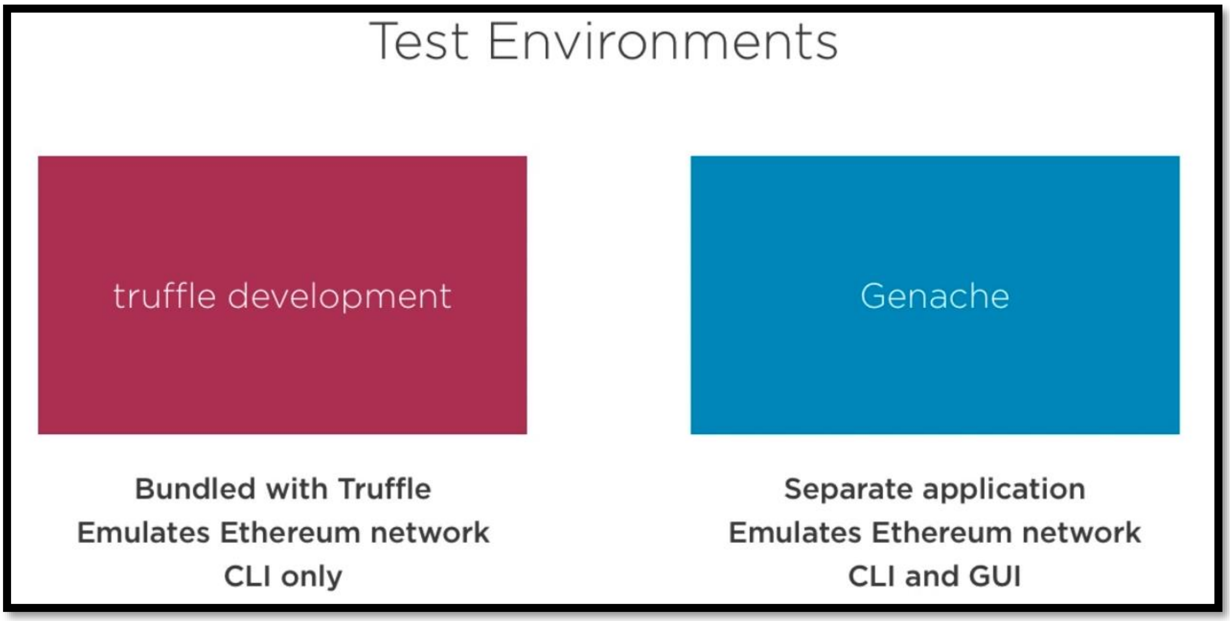



Figure 3. 13 Test Environments [114]

In Figure 3.13 Test Environment: Truffle offers a framework for developers to create and execute smart contract tests. This ensures code reliability and functionality. The Ganache (previously TestRPC) is a personal blockchain for Ethereum development, typically used with

Truffle. Developers can construct a local blockchain environment for testing and development. Ganache offers pre-funded Ether accounts for contract testing.

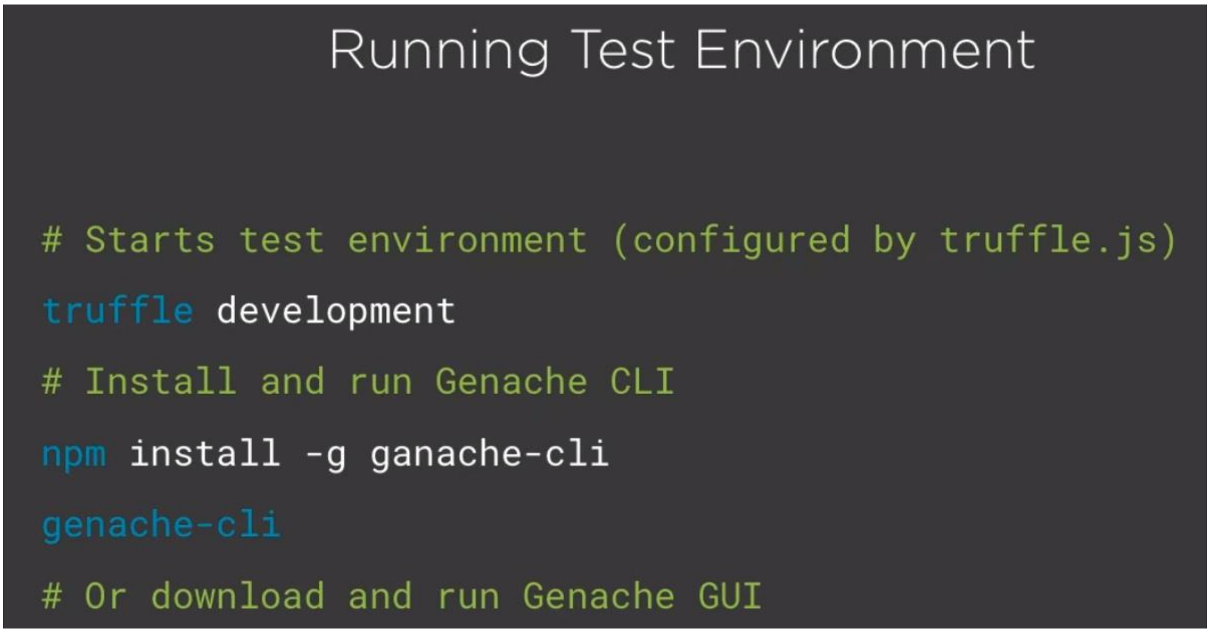



Figure 3. 14 Running Test Environment [114]

### 3.10 Distribution Consensus Algorithm

The consensus mechanism is one of the key concepts of blockchain technology. In a distributed network where the different untrustworthy user is participating in a consensus, it is required to run the system un-interrupt. As there is no central user or node that ensures the ledger on all distributed nodes is the same, an algorithm is required to ensure the ledgers on all the nodes are consistent [127]. A key challenge in blockchain technology is to determine which user can publish the next block. In permission, fewer blockchain networks, a number of publishers are competing to publish the next block, making the system challenging and complicated. This problem makes the publishers work together; the blockchain technology uses the "Consensus Model". In this section, we will describe the common approaches to reach consensus in blockchain [109]. Ethereum has undergone multiple enhancements to enhance scalability, security, and functionality. The continuing development of Ethereum 2.0 involves transitioning from proof-of-work (PoW) to proof-of-stake (PoS), which aims to improve the efficiency and sustainability of the network.

Ethereum is pivotal in the advancement of decentralised apps, the establishment of decentralised finance (DeFi) protocols, and the implementation of non-fungible tokens (NFTs).

A user must agree on the initial state of the blockchain when it joins the blockchain, which is recorded in the pre-configured (genesis) block. The blocks must be added to the system based on the agreed consensus model.

### 3.10.1 Proof of Work (PoW) Model

The proof of work is a consensus model where someone has selected to record the transaction. Prior to publishing a block, the node has to do extensive work to confirm that the node will not strike the network. The hash value of the block header of each node is calculated in PoW consensus; the consensus requires the calculated value to reach the target value. Once the node reaches a certain given value, it will publish the block, and all other nodes must confirm the correctness of the hash value. The miners in the network would append this new block to their own blockchain for successful validation. The nodes that calculate the hash value are labelled as miners, while the procedure of PoW is termed mining. In PoW consensus, miners have to do intensive work and computer calculations to give proof, which wastes too many resources. In some PoW-based blockchain networks, the nodes work collectively to reach the target hash value and split the reward [128]. It is possible due to the distribution of work between multiple nodes working collectively to share the workload and reward.

### 3.10.2 Proof of Stake (PoS) Model

The proof of stake model is based on the investment of the nodes in the blockchain system. A large amount of investment is proof the nodes want to succeed in the system and have proof of ownership in the shape of cryptocurrency. Once the user is staked, the invested currency cannot be spent. The PoS consumes less energy as there is no need to perform intensive computation as compared to PoW. The users with more stake amount are likely to publish more new blocks as the publishing of new blocks by the user is directly dependent on the amount of investment or stake in the network. The selection based on the staked amount is somehow unfair because the single richest user can dominate the network and get more reward. Many solutions have been proposed and implemented to decide which one to create the next block [129]. Some blockchains use random selection methods like multi-round voting, delegate system and coin ageing system and to choose the next block publishers [BC2].

### 3.10.3 Round Robin Consensus Model

In permissioned blockchain networks, the concept of round-robin consensus is applicable where all the nodes are trustworthy. Each node establishes the block on its turn; this model ensures that not any single node creates the majority of the blocks. This model requires less power as compare to PoW consensus model [109].

### 3.10.4 PBFT (Practical Byzantine Fault Tolerance) Consensus Model

The practical byzantine fault tolerance is the replication algorithm to tolerate Byzantine faults. A consensus model is similar to the proof of stake, where the blockchain lets the other members vote to select the next block publisher. Before selecting a new block publisher in PBFT, several rounds of voting may occur, which is a time-consuming process. The basic requirement of PBFT is that each node must be recognized to the network. The Hyperledger Fabric [130] also uses PBFT as its consensus model.

## 3.11 Challenges of Blockchain application

Despite the advantage of blockchain, there still some issues that need to be addressed to make it a robust system. Some of the problems are Scalability, Adaptability, Regulation, Privacy [21]. Limitations of blockchains are scalability and time propagation in the network as larger blocks take larger space, the trade-off between security and block is a huge challenge [127]. To achieve higher revenue, the miners of blockchains adopt a selfish mining strategy [131] and hide their mines. In an established blockchain network, it is quite difficult to change the blockchain. The data recorded in a blockchain is forever, and difficult to change even it is wrong [132].The consensus algorithms like proof of work and proof of stake are also facing challenges as the waste of electrical energy associated with it [133]. Operational risk of applying the blockchain to energy industries, this may be reflected in:

- Loss of identification and records.
- The costs of public blockchain transactions are high.
- Lack of Users and Recipients.
- Long-term lack of experience contributes to maladministration.
- Initial applications could present technical problems.
- Lack of uniform operating mode,
- reliability and safety deficiencies

## 3.12 Difference between Centralised energy systems and Decentralized energy systems

The fundamental distinction manifests in the contrasting paradigms of centralization of control and ownership in conventional systems as opposed to the decentralised, community-centric framework inherent in P2P energy trading systems. Peer-to-peer systems, in their essence, bestow a heightened sense of empowerment upon individual consumers and communities, thereby fostering the adoption of renewable energy sources. Furthermore, these systems exhibit the potential to exhibit enhanced resilience in the face of adverse circumstances.

### 3.12.1 Centralised energy system

The centralised energy system is a conventional and established framework for the generation, distribution, and utilisation of energy. Within this particular system, the generation of energy is primarily focused on a limited quantity of power plants that are characterised by their large-scale operations [134]. These power plants predominantly rely on fossil fuels, nuclear energy, or renewable sources to facilitate the production of energy. The electricity produced is subsequently conveyed by a network of high-voltage transmission lines to different regions and urban areas. Ultimately, the product is disseminated to end-users, encompassing residential, commercial, and industrial sectors, via localised distribution networks. The centralization of energy systems is characterised by several key features [135].

Central Authority: Within the context of an energy system that is centralised, a governing body, typically represented by a utility or governmental organisation, assumes ownership and assumes responsibility for the operation of the energy infrastructure. The aforementioned encompasses a comprehensive array of infrastructural components, namely power generation facilities, transmission conduits, and distribution networks.

Large-scale Power Plants: Electricity is produced in a limited number of expansive power plants, typically situated at considerable distances from the end-consumers, in order to maximise the benefits of economies of scale associated with energy generation.Unidirectional Flow: The transmission of electricity occurs in a singular direction, originating from centralised power facilities and reaching the end customers. The energy consumption of end-users is subject to limitations, and their involvement in energy generation is passive rather than active.

Centralised systems exhibit a notable degree of grid dependability and stability due to their capacity to promptly adapt to variations in demand and supply. Restricted Flexibility: The inherent centralization of the system hinders its ability to effectively adapt to the fluctuating nature of renewable energy sources such as solar and wind, which heavily rely on weather patterns.

Unidirectional Energy Transfer: The energy transfer mechanism exhibits a singular trajectory, originating from the centralised power generation facilities and culminating at the end-users.

### 3.12.2 Decentralised P2P energy trading systems

Decentralised P2P energy trading systems represent a contemporary and inventive method for facilitating energy trading and delivery. The system utilises cutting-edge technology such as blockchain, smart contracts, and DERs to facilitate direct peer-to-peer energy exchanges [136].

The fundamental attributes of decentralised P2P energy trading systems are as follows:

Peer-to-peer transactions refer to the direct interaction and exchange of energy between energy producers and consumers, resulting in the establishment of a decentralised network. This phenomenon allows individuals to transition from being solely consumers of energy to being prosumers who engage in the simultaneous production and consumption of energy [137].

Distributed Energy Resources (DERs) encompass a range of technologies, including solar panels, wind turbines, batteries, and electric cars, which have considerable importance within decentralised systems. The utilisation of distributed resources plays a significant role in both energy generation and demand management [9].

Smart contracts and blockchain technology have emerged as innovative solutions in the field of energy transfers. These self-executing agreements are designed to automate the process of energy transactions by adhering to predetermined parameters. Blockchain technology provides a mechanism for ensuring the transparency, security, and traceability of transactions [138]. The integration of decentralised P2P systems enables greater incorporation of renewable energy sources, as these systems possess the capability to readily adjust to variations in both generation and consumption of energy at the local level.

The promotion of local energy production and trading through decentralised systems contributes to the enhancement of energy resilience at the local level, hence lowering reliance on centralised infrastructure. Energy democratisation refers to the phenomenon in which individuals participating in a P2P system are afforded increased agency in their decision-making processes about energy use, pricing, and supplier selection. This empowerment of participants ultimately results in the establishment of a more egalitarian energy market.

Decentralised P2P energy trading systems are widely regarded as a viable and promising means to enhance the integration of renewable energy sources, optimise energy efficiency, and enable consumers to actively engage in the ongoing energy transition. The primary objective of these systems is to establish an energy ecosystem that is characterised by sustainability, transparency, and a strong focus on meeting the needs and preferences of customers. The differences between the suggested peer-to-peer platform and a traditional energy system, highlighting the P2P model's move towards decentralisation, customer empowerment, and sustainability.

The following figure 3.15 serves as an illustrative depiction of the comparative analysis between a conventional energy system and a prospective P2P platform.

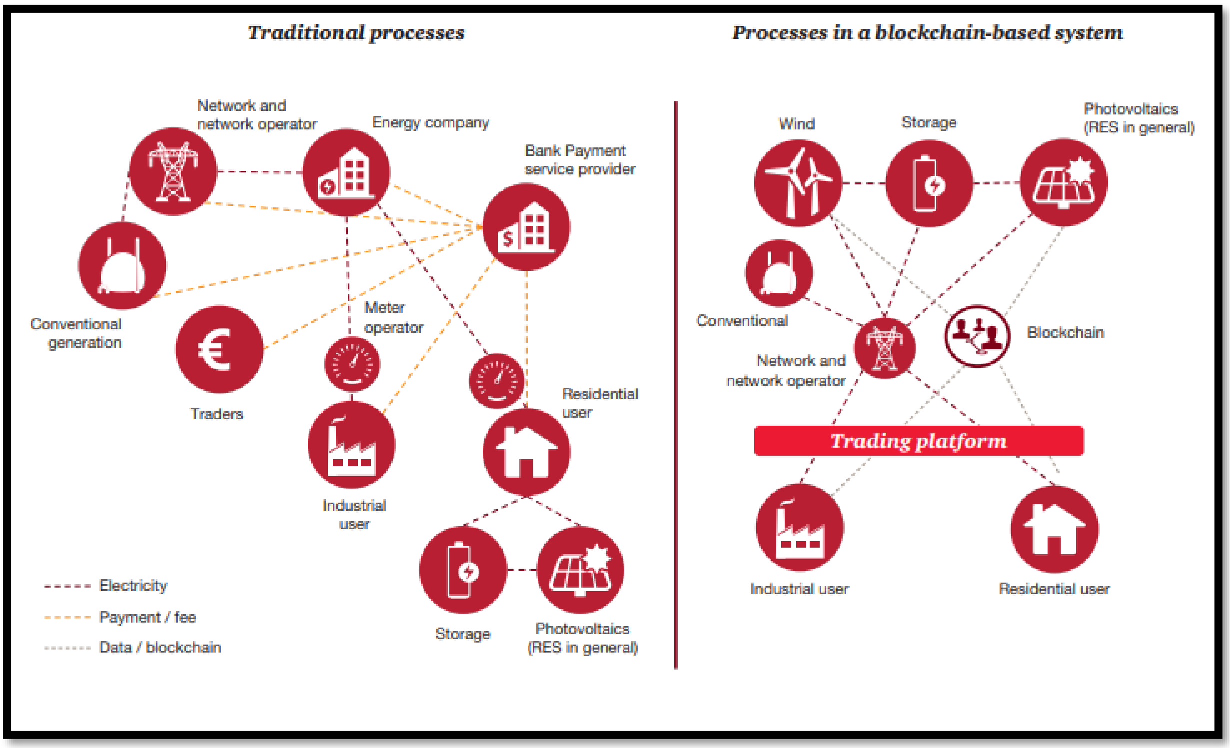



Figure 3. 15 The Traditional energy  and proposed Peer-to-peer platform [21]

### 3.13 Blockchain security in P2P Energy Trading

Blockchain security is the term used to describe the steps taken to safeguard the confidentiality and integrity of data recorded on a blockchain [139]. A decentralised digital ledger known as a blockchain keeps transparent and unchangeable records of all transactions. A cryptographic procedure is used to secure it, making sure that once a block of transactions is put into the chain, it cannot be changed or removed without invalidating the entire chain. A blockchain's security is dependent on a number of variables [140], including:

Cryptographic algorithms: The data saved on the blockchain is secured using a variety of cryptographic methods. Hashing, digital signatures, and encryption are some of these algorithms. A consensus mechanism is a method through which nodes in a blockchain network come to an understanding of the legitimacy of transactions. By requiring many nodes to validate transactions before they are added to the chain, it helps stop bad actors from interfering with the blockchain [141].

Security of the network: Blockchain networks are susceptible to attacks like 51% attacks, in which an attacker seizes control of the majority of the network's computational power. Blockchain networks employ a variety of security methods, including proof-of-work (PoW), proof-of-stake (PoS), and Byzantine fault tolerance (BFT), to thwart such assaults[140]. Smart contracts are self-executing contracts in which the conditions of the contract between the buyer and the seller are directly written into lines of computer code. The term "smart contract security" describes the steps taken to guarantee that the smart contract's code is free of errors, vulnerabilities, and malicious code [139].

In general, blockchain security is essential for the adoption of blockchain technology in a variety of businesses since it guarantees the security and integrity of the data stored on the blockchain [142].

Without the aid of a centralised organisation or middleman, P2P energy trading describes the exchange of surplus energy produced from renewable sources between specific energy producers and consumers. The security and integrity of P2P energy trading have been called into question, and blockchain technology has been suggested as a potential remedy.

The Author of [10] noted that With the rising demand for energy in distribution networks and the development of communication technology, blockchain-based P2P electricity trading promotes distributed generation resources in energy supply and improves its fairness. However, the blockchain's openness and transparency may expose P2P market participants' order information. In addition, they created a three-layer architecture for P2P electricity trading to protect private data uploaded to the blockchain with a new privacy-preserving trading technique. The three-layer architecture has physical, information, and market layers. In the information layer, an on-chain data protection method with homomorphic encryption and secure multi-party computing (SMPC) sorts and clears encrypted orders. In the market layer, grid security-constrained market mechanism checks and settles encrypted orders in continuous double auction (CDA) markets. Case studies on IBM Hyperledger Fabric confirm the method's efficacy.

In another work [143], Active distribution networks (ADNs) must optimise operating as distributed generators and power markets grow. Centralised optimisation approaches increase the computing burden in large-scale distribution networks (DNs). This research proposes a distributed operation optimisation model for blockchain-based P2P electricity trade that addresses network utilisation fees based on electrical distance. During the P2P electricity trade, the PoA consensus blockchain protects prosumers' private data. Adjustable prosumers' trade data should be provided to the DN's blockchain-based proxy entity. For dispersed network partitioning, dynamic reconfiguration with multi-level switching is offered. Dynamic reconfiguration can refresh the operation network and market structure. Adjusting network usage fee unit prices can increase P2P electricity trading with security constraints. The proposed model maximises profits and decreases computational time in distributed operation optimisation.

## 3.14 Application of Blockchain in Energy Sector

The advancement in power technologies s and transformation in infrastructure enables the integration of new technologies. The blockchains have the potential to be utilized in peer-to-peer energy trading system [80]. The concept of distributed energy generation has been implemented. The new infrastructure of power networks enabled the integration of renewable energy sources in the national grid and supported the peer-to-peer energy exchange. The sale and purchase of renewable energy among the peers need to be recorded and validated. The blockchain can help the energy traders to transfer the electricity and currency without a trusted third party, and the role of utility companies can be eliminated in P2P trading [144].

The implementation of IoT and sensor and smart meters makes the power system more energy-efficient and converted the conventional grid system into the smart grid system. The smart grid is an integral part of smart cities. The user equipped with renewable energy generation sources can trade the energy with the utility company or to other consumers via smart contracts. With the help of blockchains, the creation and validation of smart contract can be done independently without the involvement of central regulating authority. Blockchain has captured the attention of heavily regulated power industry and can be a revolutionary idea for both the consumers and utility companies [97]. A blockchain-enabled energy trading system model has been shown in below diagram .

In figure 3.16 below depicts a P2P trading system that utilises blockchain technology and is interconnected with renewable energy resources, electric vehicles (EV), photovoltaics (PV), energy storage, and consumers.

Diagram of a Peer-to-Peer Trading System based on Blockchain Technology: Blockchain Layer:

Distributed Ledger: Employs a decentralised blockchain to transparently and securely record energy transactions.

Smart Contracts: Enables the automated and decentralised execution of energy trading agreements through the implementation of smart contracts.

Sustainable energy sources:Photovoltaics (PV) refers to the process of converting sunlight into electricity using solar panels.Energy storage involves the process of storing surplus energy in batteries, which can be utilised or traded at a later time.

End-users (residential):Prosumers refer to homes that are outfitted with renewable energy sources and storage, enabling them to both consume and produce energy.

Energy monitoring is the use of smart metres and Internet of Things (IoT) devices to track and oversee the production, consumption, and storage of energy.

Peer-to-peer Trading Platform:

User Interface: Offers a user-friendly platform for consumers to access energy metrics, establish preferences, and participate in trade activities.

Marketplace: Exhibits up-to-the-minute energy pricing and enables users to submit bids and offers for the purchase or sale of energy.

Decentralised network: Peer-to-Peer Transactions: Facilitates direct transactions between prosumers, eliminating the requirement for intermediaries.

Validation Nodes: These are nodes within the blockchain network that are responsible for verifying and safeguarding transactions.

Electric vehicle integration:Electric Vehicles (EVs) have the capability to recharge their batteries during periods of low electricity demand and release stored energy when demand is high or when electricity prices are advantageous.

Automated Payments: Smart contracts facilitate the automatic transfer of funds between electric vehicle (EV) owners and energy providers.Ensuring the protection and confidentiality of data:Blockchain guarantees the immutability of transaction records, hence boosting security.

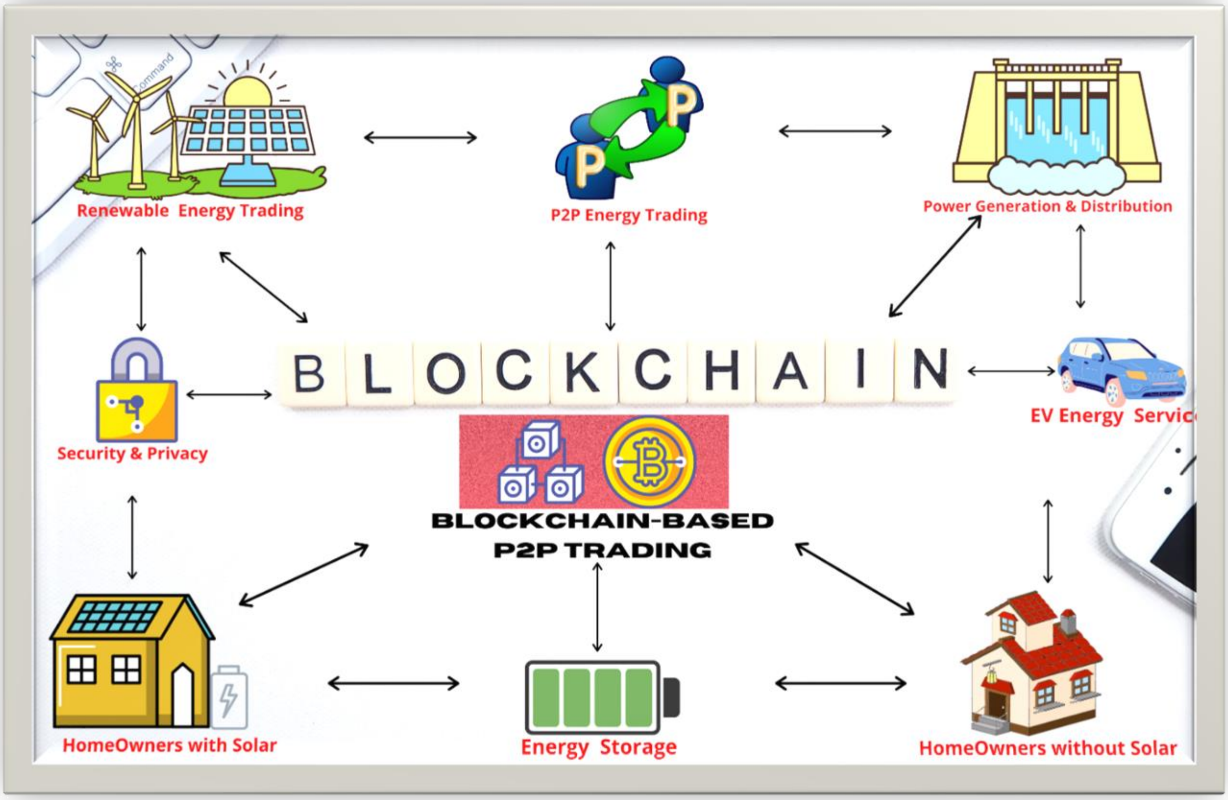



Figure 3. 16 Blockchain-based P2P Trading

### 3.15 The review of Blockchain technology trading Projects

PWC [145] defines Blockchain as an appropriated database of records or open record all things considered or advanced occasions that have been executed and shared among taking an interested party. Several studies support the implementation of a peer-to-peer energy trading platform in the energy sector. Now, this paper focuses on trial or ongoing projects on P2P energy trading platforms. According to author [109], Blockchains or distributed ledgers are emerging technologies that have generated significant attention from energy storage providers, businesses, technology entrepreneurs, financial institutions, national governments and academics. The study discusses 140 blockchain development projects and start-ups from which we build a map of the potential and importance of blockchains for energy applications. The Initiatives have been divided into various categories according to the area of operation, the implementation mechanism and the consensus approach used. Multiple organisations are running blockchain projects [12]. Example of blockchain projects are: The Enerchain project [24] in Germany focuses on Blockchain for the wholesale energy sector, Joining forces with over 40 European energy firm to trade on the peer-to-peer energy market. A blockchain framework developed by PONTON.

According to Mertz [146], Blockchain technology is a modern way of developing innovative software systems and business models. The Power Ledger Project [147] in Australia, and operating framework for emerging energy markets, is a blockchain-enabled platform for sustainable trading energy and environmental commodities. The aim is to bring the solution to renewable energy. The Internet of electricity adds intelligence to make decisions on the grid; Device identifier, Geolocation, Blockchain ID, Bid and Offer based. The Brooklyn microgrid (BMG) project [148], established by LO3 Energy, a New York-based start-up, aims to build a blockchain-based P2P trading system that will enable the business to operate.

Electricity is to be grided to hospitals, shelters, and community centres where appropriate—creating permissioned energy platform that integrates peer-to-peer, Microgrid, Distributed system operators and EV charger.  The Electron Project [149], is a London blockchain and energy expertise company, building an energy trading platform using Ethereum. The projects are operating internationally and building different projects such as the RecorDER project [149] that share assist register trading platform in the UK; also the TraDER project is a flexibility market platform to promote low carbon generation in the UK, The Groupe-Bilan Flex is a pilot demonstration program of Swiss Federal Office of Energy in Switzerland.

Finally, the London2London (L2L) project led by Local Canadian distribution and London Hydro provides transparent distribution resources in Canada. The Sun Exchange  [150] is a peer-to-peer solar leasing platform that allows the individual to generate and selling solar energy in local currency or Bitcoin (BTC) in South Africa. The Prosume project [151] also focus on decentralized energy exchange promoting new energy community models. Sun Contract is a blockchain-based platform that enables producers and consumers to trade electricity among residential houses, office facilities and businesses. The Piclo project [147] is a peer-to-peer flexibility marketplace that makes electricity grids more transparent and reliable. They join the partnership with Energy suppliers, network operators and flexibility provider. The Verv project [152] offers a peer-to-peer for social community house in Hackey -UK. This project installs solar panels on 14 houses using flexibility to test the P2P platform. EnergiToken (ETK) [153] offers a blockchain platform that rewards consumers for energy saving as involving low-carbon activities, taking public transport and using electric vehicles.

The Grid Singularity project is an international energy web foundation building an open-source platform called Decentralisation Autonomous Area Agent (D3A). A customized based energy platform to enable local connectivity on a smart and transactive grid. The D3A is an energy exchange platform that allow individual to model, simulate, and deploy a renewable energy in a local community. Also, it is based on smart contract which eliminate conflict of interest to allow all participant to trade in the same market, especially, placing bids and offers to match or clear trades. D3A beta version allows energy peripheral to trade in a scalable web app [154]. The LO3 project [155] is P2P trading of solar energy within the local community. The design application is called Pando; this provides a platform for utilities and retailers to trade in the marketplace directly to consumers. The application features make it flexible trading, powerful metrics, personal energy management, highly extendable to third parties software, simple deployment, secure and scalable. WePower [156] is a blockchain application that connects energy companies with renewable producers to meet competitive prices with transparency. Their platform provides three simple steps for buying green energy; firstly, host renewable energy producers to auctions energy. Secondly, buyers place bids, and the final successful bidder wins Power Purchase Agreements (PPAs).

Table 8 Current Blockchain Projects in the Energy sector

| Name | Participant | Location | Year Started | Aim | Size | Stage | Points |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| **Electron [149]** | Utility companies, Flexibility, Regulators, National Grid | UK | 2015 | Designed and Develop Distributed Market for Distributed Energy, Data service. | International Project. | Implemented | Combined Blockchain and energy expertise to build Flexible platform that enables: Network system, Operators, Asset owners, operators, Traders, Aggregators |
| **RecorDER[149]** | Electron Platform-Network, SP Energy, NationalGrid ESO, UK Suppliers | UK | 2019 | RecorDER creates Network innovation allowance. To improve forecasting, modelling, coordinating actions | Local | Trail | Share asset register for energy asset data and storage connected transmission and Distribution network |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **TraDER[149]** | Electron Project: EDF, CGI, ELEXON, NationalGrid ESO, Kaluza, Catapuly, | UK | 2019 | Multi-product flexibility platform | local | Trail | Pilot different energy market demand turn up, Distribution energy resources, Balance&Settlement collaborative Market and Network capacity |
| **Artemis[149]** | Electron, Gridwiz, Imperial College | South Korea | 2018 | Energy flexibility trading platform | Local | Trail | Build on Electron platform, Using price signal to incentivize demand-side and Testing energy flexibility product. |
| **London2London (L2L) [149]** | Electron Platform, London Hydro, Enmax, Gowling | Canada | 2018 | Blockchain Distributed resources for Hydro network | Local | Trail | Flexible asset management linking residential and commercial such as Batteries, Peaks and Transformers. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | WLG, Navigant | | | | | | |
| **Prosume[151]** | Suppliers | Italy | | P2P Transaction Record, IOTs enabled | Community | Local | Energy exchange platform, Using demand respond from grid balance, smart billing and Auto process |
| **Sun Contract[157]** | Sun Contract | Slovenia | 2016 | P2P Energy Trading Platform, Smart, Clean | International | Implemented | Decentralized energy market |
| **Sun Exchange[150]** | Sun Exchange | South Africa | 2015 | P2P Solar Lease Platform | International | Implemented | Buy to lease solar marketplace. Solar cell crowd sale. |
| **Verv[152]** | Verv | UK | 2015 | P2P social trading platform | Local | Trail | Using Blockchain and AI for Consumption and Production. Selling excess energy for ROI |
| **Enerchain[146]** | Eon, Enel, Ponton | Germany | 2018 | P2P Energy Trading Platform for Wholes Gas and Electricity | Europe | Implemented | Trading of wholesale energy product(B2B). |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | TSO, DSO and grids management. |
| **Piclo[147]** | Good Energy, Open utility, Powervault, AMP, Uk power network, Scottish &Southern, Western Power, Spenergy network | UK | 2018 | P2P Energy Trading Platform for Flexibility marketplace | Europe | Trail | Building smart energy for flexibility, Network operators, Suppliers and commercial contract. |
| **LO3 Energy [155]** | Shell, Braemar, Siemens, Centrica, Peci, Sumitomo | US | 2017 | P2P trading of solar energy | International | Implemented | P2P integrating Grid edge data, Utilities, DSO, Retailers |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Power Ledger[158]** | Power Ledger,POWR token, Sparkz | Australia | 2016 | P2P Market Place for Renewable energy | International | Implemented | The blockchain-enabled platform uses two digital tokens; operating system synchronizes energy transactions and payments on a global scale.<br>POWR and Sparkz maintain continuity across the Power Ledger network. Eg: 1 Sparkz =AUD$0.01, |
| **EnergiToken[153]** | EMA,FuzeX,JEM Energy, ON5, 3FEV | UK | 2018 | Blockchain Reward Token | UK | Trail | Incentive energy consumers for saving |
| **One Office** | Total, Gazprom | Europe | 2017 | European gas trading on BTL's Interbit platform | Perth | Trail | Interbit blockchain involves ing, Invoice, settlement. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Grid Singularity[154]** | Energy Web Foundation | International | 2016 | Transaction recording | | Implement | P2P energy exchange integration with IoTs, D3A |
| **Electrify** | Electrify. Asia | Southern Asia | 2017 | P2P purchase for retailers. | | Trail | Southern-Asia retail electric platform |
| **WePower[159]** | We power, Elering, | Lithuania, Estonia | 2018 | P2P energy PPA auction platform | International | Implemented | Smart energy contract and smart energy tokens, Buyer portfolio, |

### 3.16 Systematic Review on Opportunities and Challenges

To understand the nature of blockchain application, this work conducted a systematic literature review on relevant academic research and industry projects. Lu et al. [160] discussed the opportunities, challenges, and risk in the blockchain application in the energy sector. This paper identified the critical benefit as reducing transactional cost, eradicating third parties, improving transparency and efficiency. Numerous sources coming from these backgrounds describe blockchains that have the potential to offer significant benefits and creativity. The Blockchain contains a specific and unquestionable record of every exchange at any point made. To utilize an essential relationship, it is anything but difficult to take a treat from a treat container, kept in a confined spot than taking the pleasure from a treat container kept in a commercial centre, being seen by a great many individuals. The paper also identifies blockchain development in the energy sector, moving towards hybrid blockchain architecture, hybrid consensus mechanisms, and cross-platform.

As suggested by Andoni et al. [109], Blockchain is a new technology. Many organisations such as start-ups, supply firms, financial institutions, government, and academic institutions are considering deploying the Blockchain network. Blockchain can support the new business to automate their activities using smart contracts, promise transparency and secure system. As portrayed by Hagstrom and Dahlquist [161] in their examination paper entitled Scaling Blockchain for the vitality part, Blockchain is a circulated record technology where each full hub in the system downloads a duplicate of a similar record. The record is a collection of all exchanges at any point made on the Blockchain. The first idea of Blockchain was to have all exchanges on the Blockchain visible to all hubs in the system. All hubs in the system need to check an exchange for it to be finished. The exchanges are put away in the arrangement in a sequential square request when the exchange is confirmed. The journalists of this exploration paper further present three hubs of the Blockchain technology in their examination paper. Full hubs, light hubs and customers. Full hub figures all calculations were vital for checking exchanges. A light hub just downloads header information and can't confirm all information. A customer is programming that gives digital money wallets to clients.

The customers depend on full hubs confirming exchanges since the clients of wallets just can perform exchanges. Under the heading of Blockchain, the two scholars have portrayed the blockchain technology with subheadings in their abstract piece. Author Hagstrom and Dahlquist [161] portray two sorts of blockchain technology in their examination paper. Open and Private Blockchains. An open blockchain implies that anybody that downloads the Blockchain can; (1) see exchanges (2) check exchanges, (3) make exchanges. The first Blockchain made and utilized for Bitcoin is known as an open blockchain. When seeing the exchange, the addresses of the one's creation exchanges are mysterious. The information demonstrating is sum executed and time of exchange.

In their exploration paper, Hagstrom and Dahlquist [38] show the confirmation and exchanges system in detail under the subheading of check and exchanges procedure. The hubs in the system perform checking exchanges on the Blockchain. The hubs concur by arriving at accord. Diverse blockchain conventions utilize distinctive agreement calculations. The two scholars utilize visual pictures too to exhibit the confirmation and exchange process. The procedure is additionally pointed by point in their examination paper under three captions: proof of work, proof of stake and Practical Byzantine Fault Tolerance.

According to a  by Hasse et al. [21], blockchain possibilities in 16 use cases, primarily for the energy trading market without central players, instead Decentralization between customers and producers. It also allows Blockchain easier for prosumers who generate and consume renewable energy to sell Over-network. Finally, the whole energy market can be adjusted billing, retailing, evidence of origin and possession. Gaigalis and Katina [80]  study offers an initial review of the technology itself and addresses the possibilities and drawbacks. They also offer an overview of existing blockchain-related activities in major accounting firms and track important developments in this technology development.

A considerable amount of works on Blockchain focus on benefit and opportunities aspect and do not suggest the development, designed and deployment of the blockchain network. Lu et al. [160] suggested that Blockchain is bringing opportunities to reduce transaction costs and develop towards hybrid blockchain architecture, hybrid consensus mechanism and integrating into an existing system. World energy council [73] interviewed 15 companies and organizations involved in blockchain developments in the energy sector, based in the US, China, Europe, Japan and New Zealand. The findings identify blockchain technology to change the way we record and verify transactions.

In light of the preceding analysis, it can be inferred that the evidence presented supports the conclusion that the research question has been adequately addressed.

Blockchain technology serves as a formidable catalyst in the reconfiguration of various industries on a grand scale, while simultaneously engendering a paradigm shift in the manner by which energy is produced, disseminated, and consumed. The advent of blockchain technology, characterised by its decentralised and transparent nature, in conjunction with the automation capabilities of smart contracts, signifies the dawning of a novel epoch in the realm of energy trading. This transformative era is poised to be characterised by its resilience, inclusivity, and sustainability. In the face of persistent challenges, it is noteworthy to acknowledge the continuous endeavours in the realms of research, collaboration, and technological innovation. These collective efforts are diligently forging a path towards a future wherein decentralised P2P energy trading assumes a pivotal role within our energy infrastructure.

## 3.17 Summary

In Chapter Three, we go deep into blockchain technology, looking into its fundamental concepts, historical evolution, and practical applications. The Ethereum blockchain is the focus of our inquiry because of its sturdy architecture, decentralisation principles, benefits, and restrictions. This chapter also deconstructs numerous key components of Ethereum's blockchain environment, including Ethereum accounts, networks, and the native coin, Ether. Furthermore, we investigate the Agile development process, a critical framework for developing blockchain applications. The primary purpose of this chapter is to lay a solid theoretical framework for our future research initiatives centred on blockchain technology trading projects. Blockchain Fundamentals: To begin, we create a solid foundation by introducing the fundamental concepts that underpin blockchain technology. Distributed ledgers, cryptographic hashing, and the decentralised nature of blockchain networks are examples of these. Historical Context: To understand the evolution of blockchain, we must first go back in time and trace the origins of this revolutionary technology. Understanding its origins provides important insights into its rapid development and adoption. Ethereum Blockchain Architecture: Ethereum is thoroughly investigated as a pioneering blockchain platform. We describe its architecture, emphasising the decentralisation concepts that distinguish it from standard centralised systems.

Benefits and Drawbacks: Our investigation extends to analysing the benefits and drawbacks of Ethereum's blockchain technology. This in-depth examination provides us with a sophisticated grasp of its strengths and restrictions. Ethereum Components: We deconstruct the many components that comprise the Ethereum blockchain platform, explaining the roles and functionalities of Ethereum accounts, networks, and Ether, the native coin. Agile Development approach: A key focus is the Agile development approach, which is adapted for blockchain applications. We examine its concepts and practises, emphasising its adaptability to the specific needs of blockchain development.

Theoretical framework: This chapter provides the theoretical framework for our upcoming examination into blockchain technology trading projects by extensively covering blockchain technology and its underpinnings.

Chapter Three is a critical point in our study trip since it provides us with the knowledge and theoretical foundation we need to go into the practical aspects of blockchain technology trading applications. It provides us with a thorough understanding of blockchain ideas and Ethereum's architecture, laying the groundwork for the actual applications and analyses that will follow in the next chapters.

# CHAPTER 4 Research design and implementation

## 4.1 Introduction

This section is intended to provide an overview of the research design and implementation for constructing a P2P trading platform for householders with photovoltaic (PV) systems, assets, electric vehicles (EVs), and microgrids on the Ethereum blockchain framework. This study adapted an exploratory research design. As such, exploratory studies are not intended to provide definitive answers but rather to lay the groundwork for more conclusive research at a later stage [162]. Given the current uncertainty and novelty of the technology, conclusive research methods that aim to provide definitive findings about a subject would not have been feasible [162]. On the other hand, an evaluative research purpose could have been used if the objective was to determine the effectiveness of blockchain in a particular application or industry. However, because almost all blockchain projects are still in the early stages of development, it was determined that such an approach would be inappropriate.

## 4.2 Research Approach

The methodology approach being used within the research program aligns with the four stages of the design research methodology [163]. The work packages and facilitation of an iterative approach to the building of a P2P trading platform for homeowners with PV, assets, EVs, and microgrids on the Ethereum blockchain framework. Design research involves analysing, visualising, assessing, and implementing. A peer-to-peer trading network for households with solar PV, assets, EVs, and microgrids on the Ethereum blockchain is built iteratively.

The project will utilise a thorough methodological approach, principally relying on the HOMER analytic framework, to address the research topic of creating a decentralised peer-to-peer energy trading network for residential homes. The HOMER analysis will be used as a fundamental tool to evaluate and enhance the incorporation of renewable energy sources, such as solar PV systems and electric vehicles, into the proposed platform.

The next sections examine each component, offering an intricate explanation of their function in the process of growth.

- Initial Assessment: Perform an initial evaluation of the energy requirements, usage patterns, and power generating capabilities of residential dwellings that are equipped with solar photovoltaic (PV) systems, electric vehicles (EVs), and microgrids.

- HOMER Simulation: Employ the HOMER software to model different scenarios, taking into account variables such as energy generation, storage, usage, and cost ramifications. This analysis aims to ascertain the most efficient setup for the proposed peer-to-peer energy trading platform.
- Blockchain Integration: Incorporate the Ethereum blockchain into the model to guarantee transparency, security, and efficiency in the peer-to-peer energy transfers. Discover the utilisation of smart contracts to automate and authenticate transactions between participants.
- Iterative Development: Employ an iterative development methodology, integrating input from stakeholders, technical specialists, and prospective end-users. The iterative technique enables the improvement and optimisation of the decentralised energy trading model.

## 4.3 The Research Methodology

The research strategy will adhere to the four phases of design research methodology. Problem definition, exploration, concept development, and testing are included in these phases. The research programme will take an iterative approach, enabling the P2P trading platform to be continuously enhanced. The work bundles will be designed to facilitate each stage of the research, ensuring a methodical and exhaustive examination of the objectives.

## 4.4 Work Package

Work packages refer to the defined and organised tasks or activities within a research undertaking. They define the activities, deliverables, and timelines required to accomplish the project's objectives. Work bundles facilitate the subdivision of a research project into manageable units, allowing for improved planning, coordination, and progress monitoring.

The hierarchical framework of work packages is intricately interconnected with the corresponding chapters.

1. Work Package 1: Project Initiation and Scope Definition. Chapter 1 - Introduction: Provides a comprehensive overview of the historical context, theoretical underpinnings, and research goals of the study. Formulates the preliminary scope of the project and delineates fundamental objectives.

2. Work Package II: Comprehending the Energy Landscape Chapter 2 - An Exposition on Renewable Energy and Energy Costs: Delivers a comprehensive overview of various renewable energy sources, the intricate dynamics of electricity costs, and the escalating energy costs within the United Kingdom. Introduces "vehicle-to-everything" (V2X) technology and its pertinence to the research.
3. Work Package 3: Exploring Blockchain Technology Chapter 3 - Blockchain Technology: Explores the Ethereum blockchain model, which is a decentralised and distributed ledger system that utilises cryptographic techniques for secure and transparent transactions. Discusses centralized and decentralized energy systems.Examines and evaluates extant peer-to-peer energy trading models, blockchain applications, and pertinent technologies.
4. Work Package 4: Design and Proposal of the Methodological Framework and Architecture. Chapter 4 - Research Design and Implementation - Methodology: A Comprehensive Examination of the Methodological Framework for Conducting the Study. Elucidates the methodological framework, encompassing the HOMER analysis and the techniques employed for data collection. This discourse elucidates the architectural framework of a decentralised energy trading model predicated upon the Ethereum blockchain, designed to accommodate residential units equipped with solar photovoltaic systems, electric vehicles, and microgrids.
5. Work Package 5: HOMER Modelling and Peer-to-Peer Trading Optimisation. Chapter 5 - HOMER Modelling and Optimisation of Peer-to-Peer Trading Use Case: My research primarily revolves around employing HOMER modelling techniques to optimise various peer-to-peer trading scenarios. Elucidates the intricate process of model development, seamlessly integrating profound insights derived from the HOMER analysis and meticulous data collection. Integrates photovoltaic panels and energy storage systems with the electrical grid.
6. Work Package 6: Design and Implementation of Peer-to-Peer Solar Chain. Chapter 6 - Solar Chain P2P Design and Implementation: Elaborates on the design and implementation of a Blockchain-Based platform for Peer-to-Peer Energy Trading, showcasing a comprehensive understanding of the subject matter.Explores the development of intelligent contracts for the SolarChain Energy Network employing the Truffle framework. Presents a user case scenario within the Solar Chain network,

elucidating the intricate interplay of various stakeholders and the underlying technological infrastructure.

7. Work Package 7: Conclusions and Future Works - A Comprehensive Analysis and Prospects for Further Research. Chapter 7 - Conclusion and Future Directions: In this comprehensive analysis, we have synthesised and distilled the salient findings and notable contributions of our research endeavour.Explores the ramifications of the study and its prospective influence on the energy trading domain. Presents potential pathways for future investigation and advancement within the discipline.

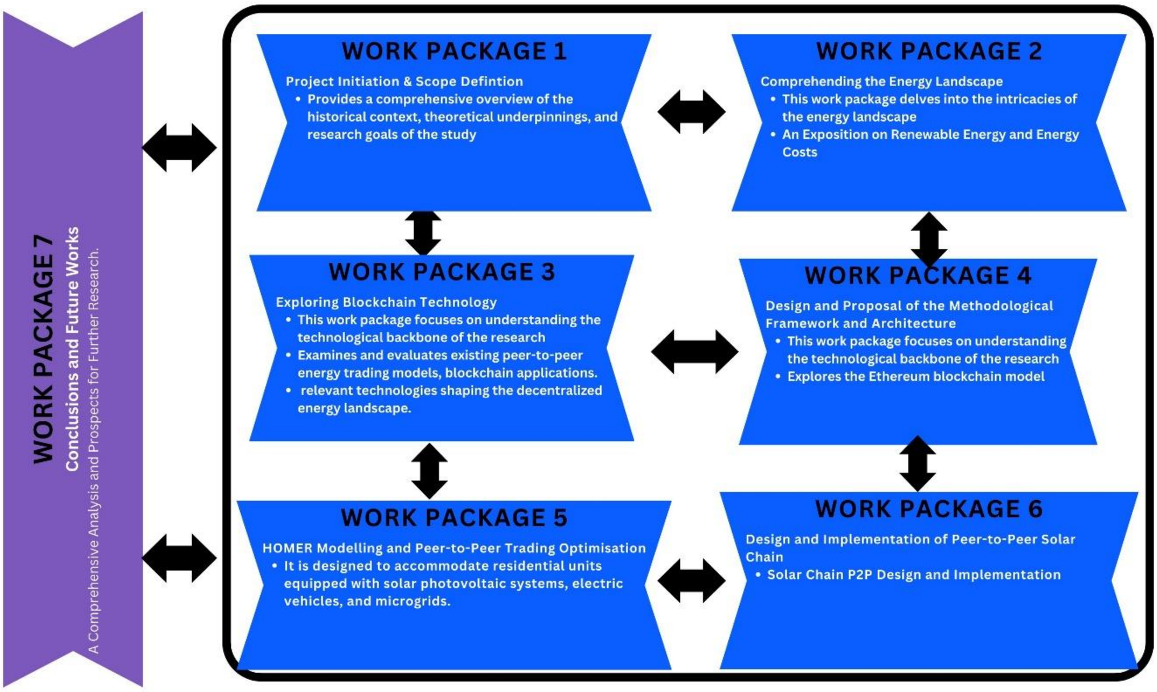



Figure 4. 1 Work Package

## 4.5 The Proposed Architecture Blockchain Based peer-to-peer energy trading platform

The architectural proposal section is critical in providing an overview of the technological framework that forms the foundation of the decentralised energy trading model. In order to solidify the narrative and effectively communicate its role within the overarching framework of the thesis, it is possible to elaborate on the importance and justification of each principal element:

A decentralised energy trading model is introduced, utilising the Ethereum blockchain as its foundation, with the intention of enabling peer-to-peer transactions between households that are outfitted with solar PV, EVs, and microgrids. By utilising critical components, this architectural design is essential to attaining the research objectives:

Smart Contracts:

Smart contracts facilitate energy trading procedures on the blockchain due to the fact that they are self-executing. This practice guarantees the trust and transparency necessary for secure peer-to-peer interactions, in addition to streamlining transactions.

Decentralised application (DApp):

Purpose: The DApp, designed to be easily understood and used by users, acts as a platform that delivers up-to-date information on energy prices and allows users to enter their bids and offers for energy. This element facilitates increased user participation and accessibility in the energy trading procedure.

Digital Metres:

Justification: For transactions to be accurate and transparent, real-time measurement of energy production and consumption at the prosumer and consumer levels is essential. Smart metres enhance the dependability and effectiveness of the decentralised energy trading framework.

The Blockchain System:

Justification: The implementation of a decentralised and distributed ledger guarantees the integrity, visibility, and confidentiality of every transaction. Selected for its resilient characteristics, the Ethereum blockchain functions as the foundational element that ensures the integrity of the complete procedure.

P2P: Peer-to-Peer Platform

Justification: The prosumer-to-consumer P2P platform, which is accessible via mobile or web applications, enables energy trading between prosumers and consumers in a seamless fashion. This facilitates increased user engagement and participation in the peer-to-peer energy market.

Communication via V2X:

Justification: Energy utilisation is optimised when electric vehicles are able to communicate with one another and the grid. This functionality facilitates dynamic energy transactions, wherein surplus energy can be sold back to the utility during periods of high demand or charged during periods of low energy prices.

Electronic Wallet:

Reason: A digital wallet serves as a critical component in the management of cryptocurrency employed in the peer-to-peer energy trading system, facilitating transactions on the platform in a secure and streamlined manner.

The Analytics of Data:

Reasoning: The implementation of real-time data analytics tools improves the quality of decisions through the surveillance and examination of patterns in energy usage and production. This facilitates the ongoing enhancement of the system as a whole.

Synopsis of the Proposed Architecture: Three-Layer Methodology

In the following section, a three-layered architecture is described, with an emphasis on the physical, virtual, and application layers. The architectural model plays a critical role in the research methodology by enabling the simulation of automated proposal processing and energy trading.

### 4.6 Overview of Proposed Architecture

In the following section, a three-layered architecture is described, with an emphasis on the physical, virtual, and application layers. The architectural model plays a critical role in the research methodology by enabling the simulation of automated proposal processing and energy trading. [164]: Figure 4.4 shows the proposed Architecture Model of the research

It is comprised of:

1. **The physical layer**

The fundamental component of the proposed architecture is the physical layer, in which prosumers actively participate in energy transactions, assuming the roles of both purchasers and vendors. A dynamic interplay between multiple entities—such as public charging stations, solar-powered residences, and the national grid—lays the groundwork for a thriving peer-to-peer energy trading ecosystem. Prosumers, who are outfitted with solar photovoltaics, electric vehicles, and microgrids, navigate this stratum deftly, capitalising on excess energy during periods of high production and engaging strategically with the broader energy market.

Justification: The collaboration between the tangible layer and the SolarChain platform fosters an atmosphere that encourages prosumers to engage actively in the peer-to-peer energy market. By enabling users to simulate and traverse a variety of scenarios, the SolarChain user interface facilitates a greater comprehension of the platform's capabilities. By means of smart contracts that facilitate secure and transparent P2P transactions among prosumers, the SolarChain platform exemplifies how decentralised energy trading has the capacity to revolutionise the way in which sustainable and efficient energy is exchanged in the future.

2. **Virtual Layer with Blockchain Technology**:

Justification: By establishing a consortium blockchain comprised of prosumers, a decentralised and transparent ledger is produced. By participating selectively in the consensus process, efficiency is maximised. However, only selected nodes (e.g., RSUs) will participate in the consensus process. A prosumer places a bid to sell energy in the energy trading market through a smart contract. The smart contract contains all the rules and market mechanisms of energy trading between two parties. This layer also includes the AI algorithms which are used to support systems to strategically make decisions for optimising system operations and achieving certain goals such as mitigating carbon emissions, saving electricity bills, improving EV battery life, improving generation profits, and predicting system uncertainties.AI algorithms play a significant role in informing strategic decision-making processes by ensuring alignment with overarching objectives such as emissions reduction and cost efficiency.

3. **Physical Layer:**

Justification: The user interface and applications essential for prosumers to engage with the system are contained within this layer. This emphasises the critical significance of applications in the translation of user requests, execution of transactions in the physical layer, and processing of those requests in the virtual layer.

Through the clarification of the underlying reasoning for each architectural element and its role in the research methodology, the narrative is fortified, thereby facilitating a more profound comprehension of the technological framework being proposed and its importance within the overarching structure of the thesis.

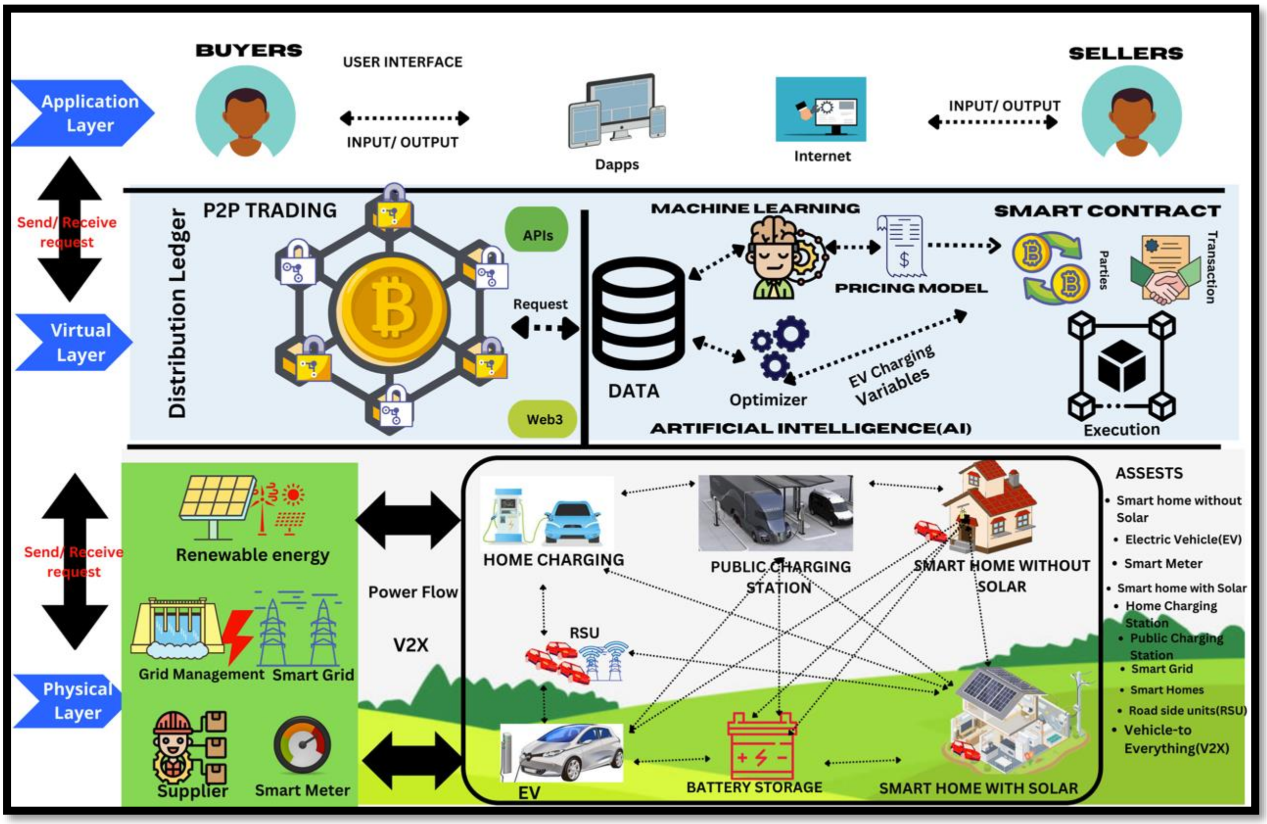



Figure 4. 2 Proposed Architecture Model

The proposed architecture would enable prosumers to generate and sell excess energy to consumers through a secure, transparent, and efficient P2P trading platform. The integration of V2G technology would further optimize energy usage, increase grid stability, and reduce energy costs for consumers.

The "SolarChain," an advanced smart contract-based P2P energy trading platform, is the central component of this dynamic environment. With SolarChain acting as the technological backbone and its design guaranteeing the safe execution of P2P transactions, prosumers have a transparent and dependable platform for energy trading. Through the use of smart contracts, SolarChain automates trade, doing away with middlemen and creating a trustworthy environment for users.

User Interface for Simulation: SolarChain offers an easy-to-use User Interface (UI) to enable users in this trading environment. Ten default smart contract buttons that each present a different simulation scenario are included in the user interface. With the help of these buttons, users can simulate different market situations and scenarios and watch how the platform behaves. This not only increases user interaction but is also a useful tool for evaluating how resilient and flexible the SolarChain platform is in various situations.

Function of the User Interface (UI) in User Interaction: The UI serves as a point of entry for prosumers, giving them an easy way to start and keep track of P2P transactions. The ten preconfigured smart contract buttons, each of which represents a different step in the trading process, allow users to engage with the SolarChain platform with ease. The user interface (UI) provides an easy-to-use interface for prosumers to purchase or sell energy, investigate market dynamics, or replicate particular scenarios. This democratises access to the advantages of decentralised energy trading.

Security and Transparency in Peer-to-Peer Transactions: Security and transparency are given top priority in every SolarChain transaction by design. Through the use of blockchain technology's built-in features, SolarChain makes sure that every P2P transaction is safely documented and permanently saved on the Ethereum blockchain. This creates a strong audit trail and gives participants assurance about the integrity of the energy trading process as a whole.

### 4.7 The Background and Development Process

The platform that has been proposed is an exciting new approach to the problem of sustainable energy. It is possible that the platform will reduce the cost of energy, improve reliability, and encourage the adoption of renewable energy sources. The system is currently being developed, and it is anticipated that it will be made available to users in the not-too-distant future.

Using smart contracts in blockchain technology, we offer a variety of secure, safe, and automated decentralised energy trading interfaces within a P2P network in this study. The Blockchain network is being developed to impact electric vehicle charging, utilise the growing EV fleet to balance the network's energy demands and give an incentive for customers to join the system. The blockchain-based energy trading system serves as a command centre for processing, governing, and trading energy transactions [165].

Figure 4.5 depicts how a proposed blockchain-based P2P energy trading network could transform the energy industry by allowing individuals or entities to trade energy directly with one another. This type of platform can use blockchain technology to establish a decentralised, transparent, and efficient system for buying and selling energy. P2P within communities.

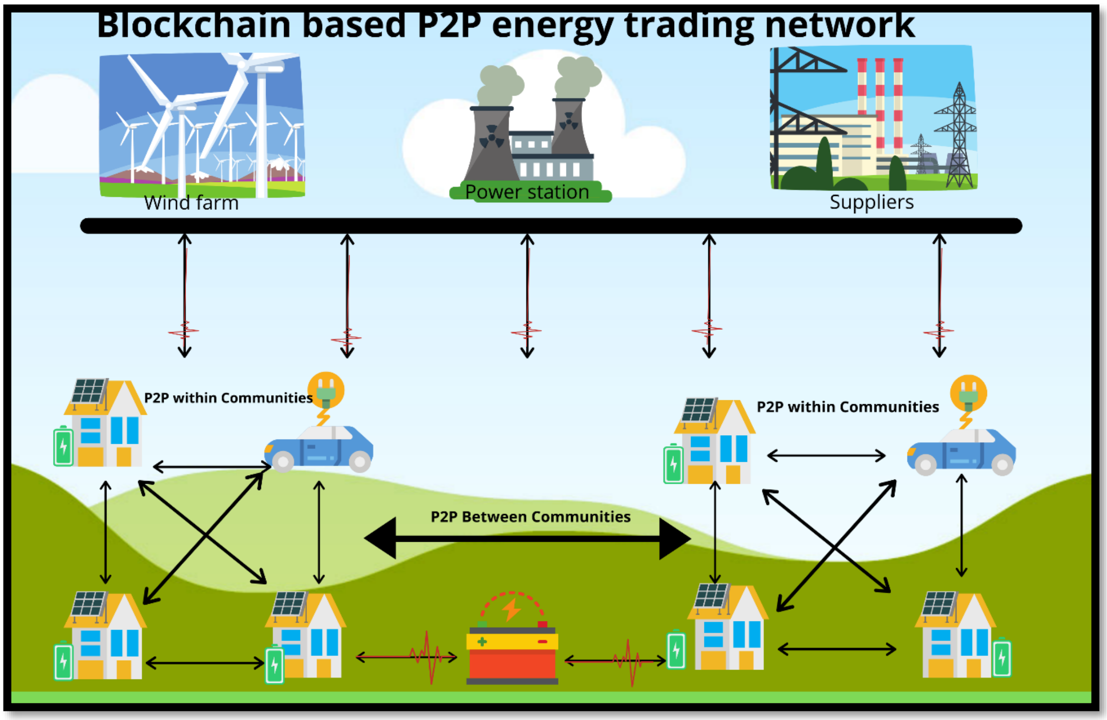



Figure 4. 3 Proposed Blockchain-based P2P energy trading platform.

### 4.7.1 Implementation process

When considering the design and implementation of a blockchain-based platform for peer-to-peer systems, careful consideration is given to the architecture's technical feasibility and scalability [166]. In the context of P2P transactions, especially with the application of Renewable energy generation regulation such as Electric vehicle (EV) characteristics, a permissioned blockchain will be more suitable than permissionless blockchain. The system will involve homeowners with solar PV or with solar PV, Electric Vehicle (EV) users will be able to sell excess energy generated. First, participant should be able to register there assets within the system. Combining a P2P energy trading platform with an aggregator can improve the efficiency and flexibility of the energy market.

Figure 4.6 depicts the role of an aggregator in the P2P economy. Marketplace Facilitation: The aggregator serves as a facilitator or mediator on the peer-to-peer energy trading market. It connects numerous providers and customers, resulting in a more liquid and dynamic marketplace.

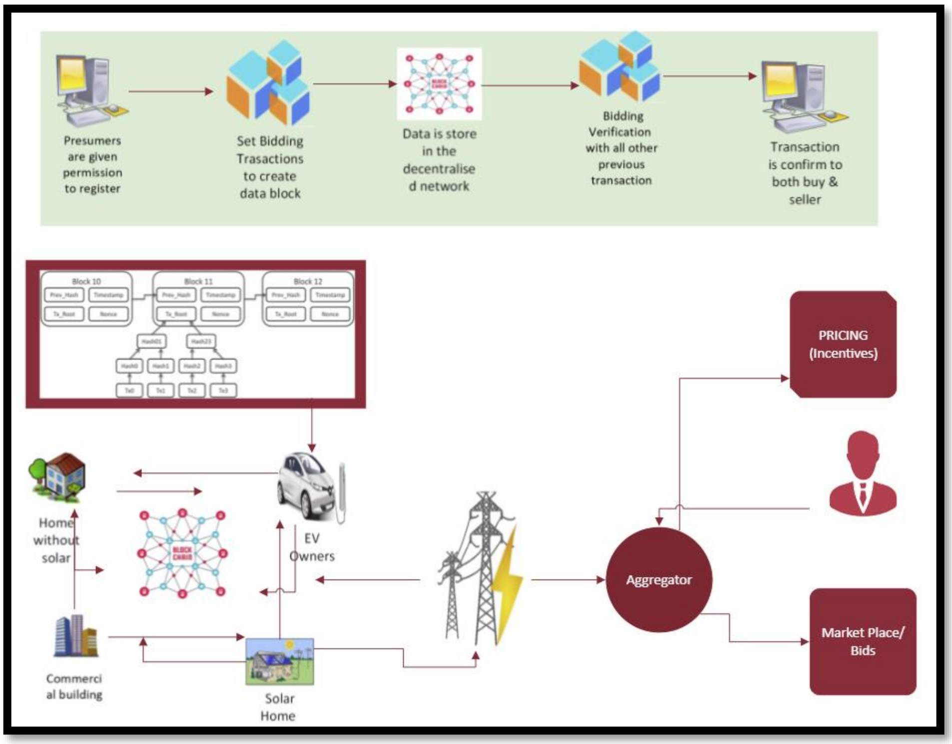



Figure 4. 4 P2P market with Aggregator

The importance of shifting from fossil fuel-based transportation systems to electric vehicles and smart cities is widely recognised. The proposed system based on blockchain, and its smart contract facility provides simplicity, safety, legitimacy, automation, trustworthiness, and privacy due to lower charging costs as well as climatic and environmental awareness [23]. The smart contract allows the system to manage bidding mechanisms like purchase and sell between prosumers. To enable proper transactions, the peer-to-peer electricity trading mechanism requires a trustworthy institution. Blockchain is a trustworthy information system that allows individuals to create transactions and store data without relying on a middleman or even the person with whom they are transacting. A trust-based connection is required between all players in the EV charging infrastructure. We've proposed a smart contract-based coin for automatic electric vehicle charging payment.

## 4.8 Summary

Chapter Four takes us from the theoretical underpinnings laid out in the other chapters to the real-world of study design and execution. This crucial chapter explores the nuances of our study methodology as well as the actual configuration and execution of the suggested peer-to-peer energy trading platform based on blockchain technology. In addition to talking about how the blockchain P2P technology was conceived and designed, we also show you the system architecture for the blockchain application and provide a thorough analysis of its features, advantages, and composition. Research Approach: The research strategy used for our study is described in this chapter. We describe the approach taken to investigate the use of blockchain technology in peer-to-peer energy trading, highlighting how it relates to our study goals.

Project Setup and Implementation: We offer advice on how to go about putting the suggested blockchain-based P2P energy trading platform into reality. This covers putting the platform in place, deploying the necessary parts, and setting up the project infrastructure all in a controlled setting. Design of Blockchain P2P Technology: We study in detail the design of blockchain P2P technology, which is the central topic of our research. We clarify the architectural concerns and conceptual framework that guided the creation of our blockchain-powered energy trading platform. System Architecture: The system architecture of our blockchain application is thoroughly examined in this chapter. We explore the intricacies of the infrastructure, emphasising its structural components and design tenets.

Blockchain Infrastructure Benefits: In this part, we discuss the advantages of using blockchain infrastructure for peer-to-peer energy trading. These benefits include increased trust, transparency, and security in energy-related transactions.

Hybrid Optimisation of Multiple Energy Resources (HOMER): We present Hybrid Optimisation of Multiple Energy Resources (HOMER) as a fundamental part of our research. This programme is used to model the long-term operation of a Micro Grid system, which is important for assessing the optimisation of energy resources.

Work Packages: Within the research framework, we talk about the idea of work packages. These well-defined and structured tasks or activities function as the cornerstones of our research project, outlining the deliverables, activities, and deadlines necessary to meet project goals.

To sum up, Chapter Four acts as a link between the theoretical knowledge and the real-world application of blockchain technology. It takes us from the theoretical understanding of the technology to the actual development of a blockchain-based P2P energy trading platform. The design ideas, system architecture, and advantages of our suggested blockchain infrastructure are explained, and HOMER—a vital tool for energy resource optimization—is introduced. Work packages help us to better structure our research efforts and make sure we make the necessary progress towards our objectives. This chapter lays the groundwork for the later stages of our inquiry, in which we will examine the platform's functionality and assess its practical implications.

# CHAPTER 5

## Homer Modelling and Optimization of P2P trading Use Case

The study investigates how to optimise energy systems for P2P trading platforms, taking into account UK energy tariffs and a variety of renewable resources like solar PV, EV,storage, and the grid.

The HOMER modelling and optimisation portion of the project are crucial elements focused on refining energy systems for P2P trading platforms. This inquiry focuses on the complexities of the energy sector in the UK, taking into account many issues such as energy pricing and the wide range of renewable resources, including solar PV, electric vehicles (EVs), storage options, and the conventional power grid. The following story seeks to clarify the fundamental elements and goals of this phase:

Contextual comprehension: The energy sector in the UK is undergoing fast changes, with a growing focus on sustainable and decentralised energy solutions. In light of this context, the paper examines the intricacies of optimising energy systems specifically for peer-to-peer trading platforms. This optimisation is guided by both the distinctive features of the UK energy market and the varied assortment of renewable resources available to prosumers.

The HOMER modelling approach relies on the use of a robust simulation software called HOMER, which is fundamental to this inquiry. This tool facilitates a thorough examination of several situations, taking into account the interaction between energy generation, storage, usage, and related expenses. The utilisation of the HOMER modelling approach is crucial in designing an energy system that is both efficient and economically feasible in the setting of peer-to-peer trading.

The reaserch acknowledges the importance of utilising various renewable resources that are abundant in the UK. Solar photovoltaic (PV), being an environmentally friendly and plentiful energy source, plays a significant role in the modelling procedure. Moreover, the incorporation of electric vehicles (EVs) into the energy system introduces a dynamic element, enabling the efficient utilisation of energy and the possibility for EVs to actively participate in peer-to-peer trade. Storage systems are essential for maintaining a stable energy supply by compensating for the intermittent nature of renewable energy output.

Analysis of UK Energy Tariffs: To account for the realities of the UK energy market, the study includes a thorough examination of energy tariffs. Gaining a comprehensive understanding of tariff structures is crucial for maximising the economic efficiency of peer-to-peer trading. The HOMER modelling incorporates different tariff rates, peak demand periods, and the changing costs related to conventional grid usage, creating an energy system that adapts intelligently to market dynamics.

Optimisation for P2P Trading Platforms: The primary objective of this phase is to enhance the energy system to ensure smooth integration into P2P trading platforms. Optimisation involves not just achieving cost-efficiency, but also taking into account sustainability, reliability, and adaptation to the ever-changing nature of P2P transactions. The HOMER modelling results offer valuable insights into the optimal setup of the energy system, assisting in the creation of a platform that meets the goals of prosumers involved in decentralised energy trading.

The study will compare two models, Model A and Model B, which both have grid connection, solar panels, and battery storage. Electric vehicles (EV) are also included in Model B.

## 5.1 Modelling of the Distribution of energy resources (DERs) within a Peer-to-Peer system

This section introduces the mathematical model that represents the operation of distributed energy resources (DERs) within a smart home, including plug-in electric vehicles (PEVs), smart thermostats, photovoltaics (PVs), and battery energy storage systems (BESSs), as well as the derivation of the peak demand for a local Manchester community. In practical terms, the primary concern of DSOs regarding DERs possessed by homeowners is that their operational schedules are typically uncontrolled [108].As a result, it's critical to develop models that explain how the aforementioned DERs function so that baseline load profiles for a community of smart homes can be created and the community's maximum peak demand can be determined.

Small-scale electrical supply or demand resources that are connected to the electric grid are known as distributed energy resources or DERs. They can be employed individually or collectively to add value to the grid because they are power generation resources that are typically situated close to load centres [38].The model uses a mathematical model of the DERs within P2P trading platform , including Electric vehicle-to Grid (V2G), Solar home, Small wind farms, Battery storage and Microgrid.

## 5.2 Model Descriptions

This research investigates two distinct microgrid models, each designed to explore specific aspects of energy resource management and system resilience.

Microgrid and distributed energy system optimisation is the primary focus of the HOMER Pro software. HOMER software employs these equations to estimate the net present cost of suggested energy system topologies. HOMER can assess the economic viability of energy system designs by discounting annualised expenses over time. Users are able to model and analyse solar PV systems and their individual components. The models are constructed to simulate a home's residential community situated in Manchester, United Kingdom.

### 5.2.1 The Optimization function.

The present study addresses the multi-objective optimisation problem relating to the scheduling of household appliances with the aim of minimising electricity expenses for prosumers on P2P trading platform. The problem formulation encompasses several key components, namely the objectives, limitations, and alternative approaches.

**Objective Functions**:

The optimisation problem is designed to attain the following objectives.

Minimise Net Present Cost (NPC):The net present cost (NPC) takes into account the complete expenses and benefits of the system during its lifetime, including the time value of money. This goal is to develop a scheduling method that decreases the entire lifetime expenses of electricity usage. The net present cost (or life-cycle cost) of a Component is the present value of all the costs of installing and operating the Component over the lifetime of the project, minus the present value of all the revenues that the Component earns over the lifetime of the project. HOMER computes the net present cost of each system Component and of the entire system.

Net present cost (NPC) is the discounted sum of the annualised cost (Can) over the system's lifespan (L). The discount factor d(i, L) considers time value of money.

The equation for NPC is:

$$C_{an} = \delta\ (i, L), C_{NPC} \qquad 1$$

Where the term d(i, L) in Equation is a factor based on the interest rate i and system lifespan L is calculated.

$$NPC = \sum pv\ cost - \sum Pv\ revenues \qquad 2$$

Where:

∑ represents the sum over the given time intervals.

PV Costs is the present value of all incurred costs.

PV Revenues is the present value of all generated revenues.

Where the term d(i, L) in Equation is a factor based on the interest rate i and system lifespan L is calculated.

Present Value of cost (PV Costs)

$$PV\ Costs = \sum (Ci\ /(1 + r) \curlywedge_i) \qquad 3$$

Where:

Ci is the Cost expense for the year ‘i’

The discount rate is r.

The year is i.

Present Value of Revenues (PV Revenues)

$$PV\ Revenues = \sum (Ri\ /(1 + r) \curlywedge_i) \qquad 4$$

Where:

Ri is the Revenue expense for the year 'i'

The discount rate is r.

The year is 'I'.

**Minimise Energy Costs:**

The goal is to reduce the direct energy cost associated with appliance electricity consumption. This entails optimising appliance schedules so that energy is used during low-cost periods.The fees (rates) that the utility bills customers for the energy loads they use are referred to as the cost of electricity. It is a measurement of the costs incurred when using electrical equipment and appliances.

**Loads on Non-Shiftable and Shiftable Appliances:**

Loads for non-shifting appliances: Appliances that have set operating hours and cannot be rescheduled are referred to as non-shiftable appliances. They constantly need energy, and it happens at regular times.

Appliance Shiftable Loads: Appliances that can be scheduled to run at various times are known as shiftable appliances. Their energy use can be moved to times when electricity is less expensive.

Equation : The formulation of the optimisation problem. The goal of the optimisation problem is to reduce the cost of power by planning the operation of appliances while taking both shiftable and non-shiftable loads into account.

Formula :

$$\mathrm{Min}\sum a = 1Na\sum t = 1TYap(t) * \rho * EPricea(t). \qquad 6$$

where:

Yap(t) is a binary variable that represents the state of the appliance at time t (1 for ON, 0 for OFF).

is a scaling factor that could have something to do with unit conversion or normalisation.

The cost of the electric energy used during the period t is represented by EPrice(t).

Minimise Carbon Emissions:

This goal aims to reduce the carbon emissions caused by power consumption. The scheduling method helps to a lower carbon footprint by minimising energy consumption during high-emission periods. The assessment of pollutants discharged into the air by HOMER, an energy modelling software, requires taking into account several types of emissions related with energy generation.

$$CE = \lambda E_{purchase} \quad 7$$

## 5.3 Mathematical models of the DERs

The provided mathematical model accurately represents the dynamics of Distributed Energy Resources (DERs) in a smart house environment. Now, let's analyse the fundamental components of the model:

Variables:

k: A discrete time index representing the sequence of time points.

m: An index that represents a collection of intelligent residences.

n: Index denoting a composite of Distributed Energy Resources (DERs) present in a smart home.

*c_grid(t): Cost of grid electricity at time t.*

*c_CH: Cost of charging.*

*c_DIS : Cost of discharging*

*c_BESS : Cost associated with the state-of-charge (SoC) of a Battery Energy Storage System*

*c_EV: Cost related to Electric Vehicle (EV) Soc*

*c_SH: Cost related to smart thermostat temperature deviation.*

and *c_PV: Cost related to PhotoVoltaic (PV) generation.*

In this model: *c_grid(t), c_CH, c_DIS, c_BESS, c_EV, c_SH,* and *c_PV* represent the cost of grid electricity, charging, discharging, BESS state-of-charge *(SoC), EV SoC,* smart thermostat temperature deviation, and PV generation, respectively. T is the total number of time steps in the simulation, *Δt_EV* and *Δt_BESS* are the time steps for the EV and BESS simulations,

In order to calculate the amount of energy used or stored during a specific time period, it is necessary to discretize the dynamic voltage of the battery by extracting data from the discharge/charge curve of the battery. Due to the scarcity of specific data regarding the discharge/charge curves of real EV batteries at various current levels, this study employs the simplified generic model for rechargeable batteries proposed by Tremblay, Dessaint, and Dekkich [167-170].

DER operation binary variables:

χ_EV,n ∈ {0,1}, χ_BESS,n ∈ {0,1}

Objective function:

$$\begin{aligned} minimize\ \Sigma\_t &= 1\hat{}T\ (c\_grid(t)\ *\ P\_grid(t))\ +\ \Sigma\_t \\ &= 1\hat{}T\ (c\_CH\ *\ P\_CH(t))\ +\ \Sigma\_t \\ &= 1\hat{}T\ (c\_DIS\ *\ P\_DIS(t))\ +\ \Sigma\_t \\ &= 1\hat{}T\ (c\_BESS\ *\ \Delta SoC\_BESS(t))\ +\ \Sigma\_t \\ &= 1\hat{}T\ (c\_EV\ *\ \Delta SoC\_EV(t))\ +\ \Sigma\_t \\ &= 1\hat{}T\ (c\_SH\ *\ \Delta T\_SH(t))\ +\ \Sigma\_t = 1\hat{}T\ (c\_PV\ *\ P\_PV( \end{aligned} \quad (8)$$

**POWER DEMAND FROM LOADS:**

"Power demand from loads" denotes the quantity of electrical power that is necessary for the functioning of electrical devices, appliances, and systems connected to the grid. Power demand is a crucial component of energy usage and is affected by several factors, such as the type and quantity of electrical equipment being utilised, their power ratings, and the duration of their operation [171, 172]. The power demand from loads is the sum of the power consumed by all appliances and equipment in the smart home. This can include lighting, HVAC systems, kitchen appliances, entertainment systems, and more. Real-life examples could include turning on the lights or using a dishwasher, which would increase the power demand. Each client has two types of loads: inelastic (lighting) and elastic (dishwasher). Customers aim to reduce their costs by operating elastic appliances during lower-priced periods while considering other consumptions [171].

Power Balance constraint:

$$P\_grid(t) + P\_CH(t) - P\_DIS(t) - P\_PV(t) - P\_SH(t) = \Sigma\_n\, P\_EV,n(t) + \Sigma\_n\, P\_BESS,n(t) \qquad 9$$

where n is the index for each DER type.

$$P\_min\_BESS \leq P\_BESS,m,n(k) \leq P\_max\_BESS,m,n \qquad 10$$

**BESS MODEL**

Power charging and discharging of BESSs:

Battery energy storage systems (BESSs) can store excess energy from PV systems or charge during periods of low electricity demand and discharge during periods of high demand. This formula represents the amount of power being charged or discharged by the BESSs. An example could be charging the BESS during the day when the PV system is generating excess energy and discharging it in the evening when the energy demand is higher [170].

Constraints on BESSs and EVs:

These formulas represent the minimum and maximum limits on the power output of the BESSs and the state of charge (SoC) of both BESSs and EVs. These constraints ensure that the BESSs and EVs operate within safe and recommended limits set by the manufacturer. An example could be the BESSs being limited to a certain power output to prevent overheating or damage to the system[167, 170, 172].

BESS charging/discharging constraint:

$$SoC\_min\_BESS,n \leq SoC\_BESS,n(t) \leq SoC\_max\_BESS,n \quad 11$$

$$SoC\_BESS,n(t = SoC\_BESS,n(t-1) + (\eta\_CH\_BESS,n * \chi\_BESS,n * P\_BESS,n(t-1)) / \Delta t\_BESS - (\eta\_DIS\_BESS,n * (1 - \chi\_BESS,n) * P\_BESS,n(t-1)) / \Delta t\_BESS$$

$$P\_min\_BESS,n \leq P\_BESS,n(t) \leq P\_max\_BESS,n$$

Power output:

$$P\_min\_BESS \leq P\_BESS,m,n(k) \leq P\_max\_BESS,m,n \quad 12$$

State of charging (SoC):

$$SoC\_min\_BESS,m,n \leq SoC\_BESS,m,n(k) \leq SoC\_max\_BESS,m,n \quad 13$$

SoC equation:

$$SoC\_BESS,m,n(k) = SoC\_BESS,m,n(k-1) + (\eta\_CH,m,n * \chi\_BESS,m,n * \quad 14$$

$$P\_BESS, m, n(k-1)) \,/\, \Delta t \;-\; (1/\eta\_DIS, m, n) \,*\, (1 - \chi\_BESS, m, n) \,*\, P\_BESS, m, n(k-1) \,/\, \Delta t \qquad 15$$

where η_CH,m,n and η_DIS,m,n are the charging and discharging efficiencies, respectively; χ_BESS,m,n is a binary variable that equals 1 for charging and 0 for discharging; Δt is the time step.

**EV MODEL**

Power charging of EVs:

Plug-in electric vehicles (EVs) can also be charged using excess energy from the PV system or during periods of low electricity demand. This formula represents the amount of power being used to charge the EVs. An example could be charging an EV overnight when the energy demand is low [173, 174].

EV charging constraint:

$$SoC\_EV, n(t0) \;\geq\; SoC\_des\_EV, n \qquad 16$$

$$SoC\_EV, n(t) \;=\; SoC\_EV, n(t-1) \;+\; (\eta\_CH\_EV, n \,*\, \chi\_EV, n \,*\, P\_EV, n(t-1)) \,/\, \Delta t\_EV \;-\; (\eta\_DIS\_EV, n \,*\, (1 - \chi\_EV, n) \,*\, P\_EV, n(t-1)) \,/\, \Delta t\_EV$$

$$P\_min\_EV, n \;\leq\; P\_EV, n(t) \;\leq\; P\_max\_EV, n$$

Power consumption:

$$P\_EV, m, n(k) \;=\; P\_des\_EV, m, n(k) \;-\; P\_grid, m, n(k) \qquad 17$$

State of charging (SoC)

$$SoC\_min\_EV,m,n \leq SoC\_EV,m,n(k) \leq SoC\_max\_EV,m,n \quad 18$$

SoC equation

$$SoC\_EV,m,n(k) = SoC\_EV,m,n(k-1) + (\eta\_CH,m,n * \chi\_EV,m,n * P\_EV,m,n(k-1)) / \Delta t \quad 19$$

where P_des_EV,m,n(k) is the desired power consumption, P_grid,m,n(k) is the power supplied by the grid, and χ_EV,m,n is a binary variable that equals 1 for charging and 0 for discharging.

**POWER GENERATION FROM PV SYSTEMS**

The power generation from photovoltaic (PV) systems is the amount of electricity generated by solar panels installed on the home's roof. This power can be used to meet the home's energy demands or fed back into the grid. An example could be a sunny day when the solar panels generate more electricity than the home needs, allowing excess energy to be exported to the grid.

Constraints on power demand and generation:

These formulas represent the minimum and maximum limits on the power demand from loads and power generation from PV systems. These constraints ensure that the home does not consume or generate more power than it is capable of handling. An example could be the PV system reaching its maximum generation capacity on a very sunny day and therefore not being able to generate any more electricity[175] .

PV generation constraint:

$$P\_min\_PV \leq P\_PV(t) \leq P\_max\_PV \quad 20$$

**POWER CONSUMPTION OF SMART THERMOSTATS**:

Smart thermostats can automatically adjust the temperature of the home to reduce energy consumption during periods of low electricity demand. This formula represents the amount of power being consumed by the smart thermostats. An example could be the smart thermostat turning off the HVAC system during a period of low demand to reduce energy consumption [176].

Smart thermostat temperature control constraint:

$$T\_min\_SH \leq T\_SH(t) \leq T\_max\_SH \qquad 21$$

$$\Delta T\_SH(t) = T\_SH(t) - T\_setpoint(t)$$

$$\Delta T\_SH(t) = \Delta T\_SH(t-1) + (\eta\_heat * P\_heat(t)) / C\_SH$$

$$P\_heat(t) = K\_SH * \Delta T\_SH(t) + P\_base\_SH$$

where T_setpoint(t) is the desired temperature setpoint, η_heat is the thermal efficiency, C_SH is the heat capacity, K_SH is the thermal conductivity, and P_base_SH is the power consumed by the smart thermostat when it is not actively heating or cooling.

**Solar PV model in Homer**

The modelling of input and output for solar photovoltaic (PV) systems. Photovoltaic systems harness solar energy through the utilisation of solar panels, hence facilitating the conversion of sunlight into electrical power. The electrical output of a photovoltaic (PV) system is influenced by several factors, encompassing sun irradiation, temperature, shade, and the inherent features of the PV panels. In this study, the HOMER programme was employed to determine the output power of a photovoltaic (PV) system [177]. The calculation incorporates multiple components, such as the rated capacity of the photovoltaic (PV) module, its derating factor, the global solar radiation incident at the module's working temperature, and additional characteristics.

An equation relating to photovoltaic (PV) power generation. Let's broken down the equation's elements:

Each variable is broken down as follows:

$P_{pv}$ : Photovoltaic (PV) output power.

$y_{pv}$ : PV panel performance ratio or yield factor that represents efficiency and losses.

$f_{pv}$ : Fill factor, a metric representing the efficiency of a solar cell.

$G_T$ : The amount of solar irradiance or sunshine that falls on the PV panels.

$G_{T,stc}$: Standard Test Condition solar irradiance, a reference value utilised for PV panel performance assessment.

The equation effectively determines a photovoltaic system's power production by taking into account the performance ratio, fill factor, and the ratio of actual solar irradiance to solar irradiance under typical test conditions.

$$P_{pv} = y_{pv}\, f_{pv} \frac{G_T}{G_{T,stc}} \qquad (22)$$

**Grid and Net Metering with Homer Grid**

With net metering, you can sell excess electricity to the grid and be credited with the retail price. Selling excess energy back to the grid causes your electricity metre to effectively and sometimes physically run backwards. The remaining balance (purchases minus sales) is what you'll be charged at the end of the monthly or annual billing cycle. The utility will compensate you at the sellback price, which is normally equal to the wholesale or "avoided cost" of power, or zero, if the "net grid purchases" value is negative, meaning you sold more than you bought during the billing period.

The Grid page enables you to specify the grid in a variety of ways:

You can specify a constant power price, sell back price, and sale capacity in simple rates mode. Real time rates specify hourly pricing by importing a properly formatted text file containing time-series data (requires Advanced Grid module). Scheduled rates permit varying prices at various times of the day and month (requires Advanced Grid module). Grid extension mode compares the cost of a grid extension to the cost of each system configuration in the model (requires Advanced Grid module).

In addition to the rates, you can access the following grid properties by selecting the corresponding tab:

Parameters includes options for costs and capacity based on the specified rate type. Demand Rates includes modelling options for demand charges. Only the Real time rates and Scheduled rates modes have access to this tab. Its contents vary depending on the selected rate mode. Reliability provides options for modelling a grid with random disruptions that is unreliable. Only the Real time rates and Scheduled rates modes have access to this tab. In terms of grammes per kilowatt-hour, Emissions enables you to specify emission factors for several pollutants.

**Scheduled Rates**

The Parameters tab for Scheduled Rates in the Advanced Grid module includes Sale capacity, Purchase capacity, Distributed Generation Costs, Systems to Consider, Maximum net grid purchases, and Grid Extension Costs.

| Variable | Description |
|---|---|
| Net Metering | Select this option to base grid energy charges on net usage. |
| Net purchases calculated monthly | With this option net usage is calculated monthly. |
| Net Purchases Calculated Annually | With this option net usage is calculated annually. |

Figure 5. 1 Scheduled Rate in HOMERS

### 5.3.1 The Community load profile

According to Ofgem data [52], the average UK household contains 2.4 people and uses 8-15 kWh of electricity. This equates to an annual power use of 2,900- 3400 kWh. The same calculation performed by Ofgem shows that the average monthly consumption would be 242 - 336 kWh of electricity.

FIT:

The Maximum AC power out of solar

2.6kW to 3.7kW (2600W to 3700w)

2.8kW to 5.0kW (3800W to 5000w)

5.1kW (5100W)

Table 9 Energy consumption in different types of households in UK[44]

| Type of Home | Average energy consumption (kWh) |
|---|---|
| End Terrace | 344 |
| Mid-Terrace | 2770 |
| Flat | 2829 |
| Semi-detached | 3847 |
| Bungalow | 3866 |
| Detached House | 4153 |

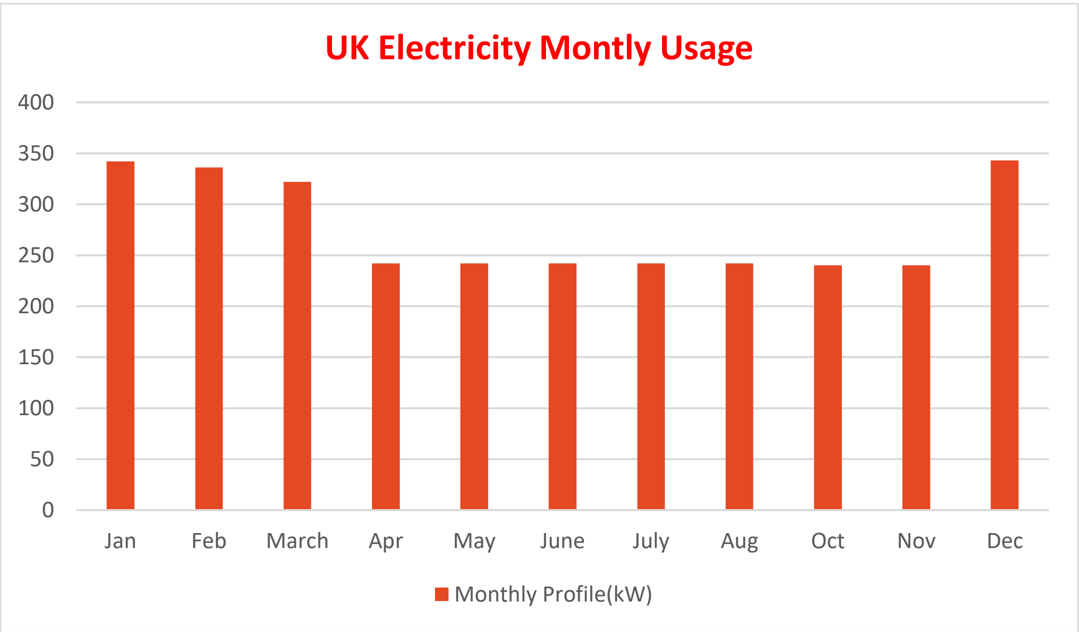



Figure 5. 2 UK Electricity – Monthly usage

Temperature

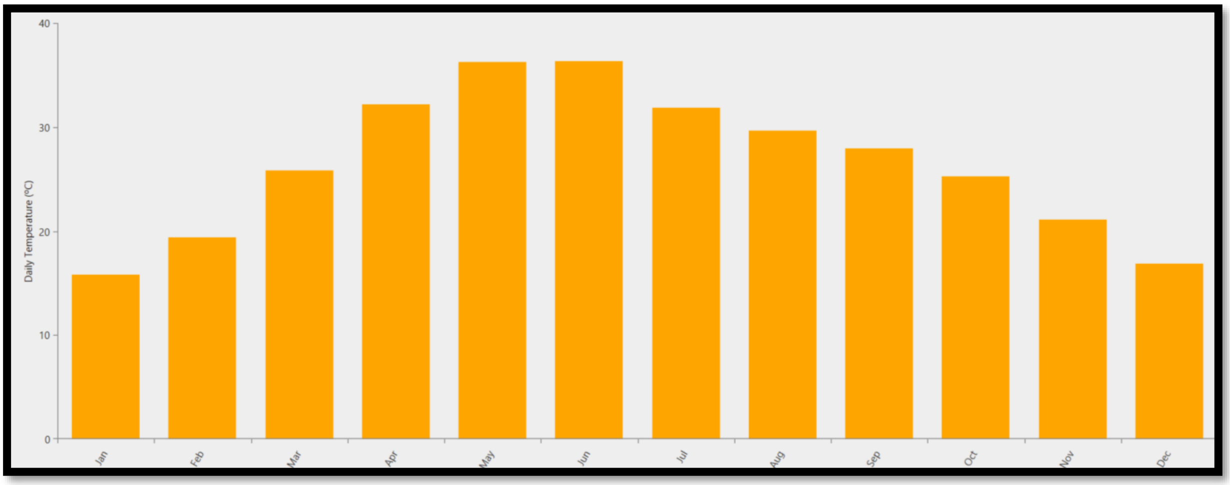



Figure 5. 3Monthly Temperature- UK

Solar GHI Resource

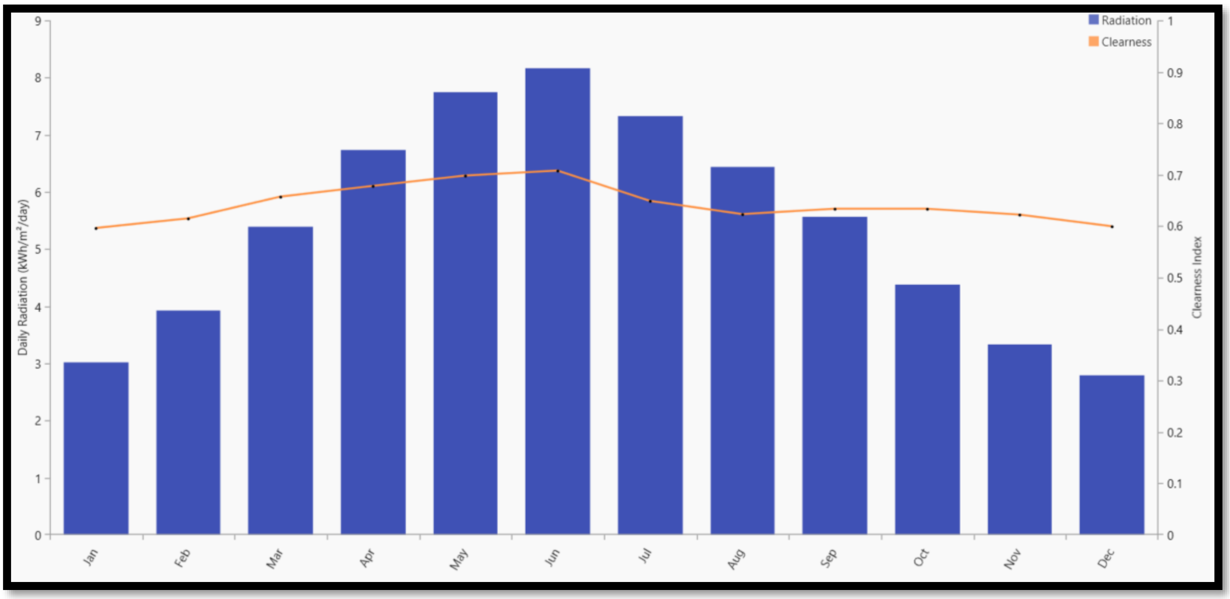



Figure 5. 4 Monthly Average Solar Global Horizon Irradiance (GHI)

## 5.4 Model A: Grid Connection, Solar, and Battery storages

Model A integrates solar panels and battery storage with the grid.

(UK FIT PV): Photovoltaic (PV) System

A photovoltaic (PV) system is made up of solar panels that convert sunlight to electricity. The measure of 1,386 kW indicates the solar panels' capacity to generate electricity under optimal conditions. FIT (Feed-in Tariff) in the United Kingdom presumably refers to a government incentive programme that compensates users for the renewable energy they generate and feed back into the grid.

Battery Storage System (kWh Li-ion Generic):

The excess electricity generated by solar panels is stored in batteries for later use. The term "Generic kWh Li-Ion" refers to a lithium-ion battery with a kWh capacity. The presence of 253 strings indicates a substantial quantity of storage capacity, given that each string may consist of multiple batteries connected in series or parallel.

System Converter (Large, Generic Converter):

A system converter, also known as an inverter or converter, transforms the direct current (DC) electricity generated by solar panels or stored in batteries into alternating current (AC) that is compatible with the electrical infrastructure or for local consumption. The large size of 9,999,999 kW may indicate that the converter is capable of handling a significant quantity of energy.

Peak Shaving Dispatch Strategy (HOMER):

The HOMER software is likely an energy optimisation utility used to model and analyse various energy generation and consumption strategies. Peak shaving is a strategy in which the battery storage system is charged during periods of low energy demand and discharged during periods of peak energy demand in order to reduce the overall demand from the grid. This can reduce electricity costs by preventing high-demand fees.

Utilities (General - Time of Use - Off-Peak - Demand Metered):

This section describes the pricing model for utilities:

The term "Time of Use" implies that electricity rates vary by time of day, with various rates for peak and off-peak hours.

"Super Off-Peak" refers to an additional pricing tier for periods when electricity demand is extremely low.

The term "Demand Metered" indicates that the utility may charge based on the utmost demand (peak load) during a given period.

Table 10 System Architecture for Model A

| Component | Name | Size | Unit |
|---|---|---|---|
| PV | UK FIT PV | 1,386 | kW |
| Storage | Generic kWh Li-Ion | 253 | strings |
| System converter | Generic large, converter | 9,999,999 | kW |
| Dispatch strategy | HOMER Peak Shaving | | |
| Utility | General - Time of Use - Super Off-Peak - Demand Metered | | |

Base system : Grid _ Connection

Proposed System : Grid Connection, Solar, and Battery storages

## 5.5 Simulation Result of Model A

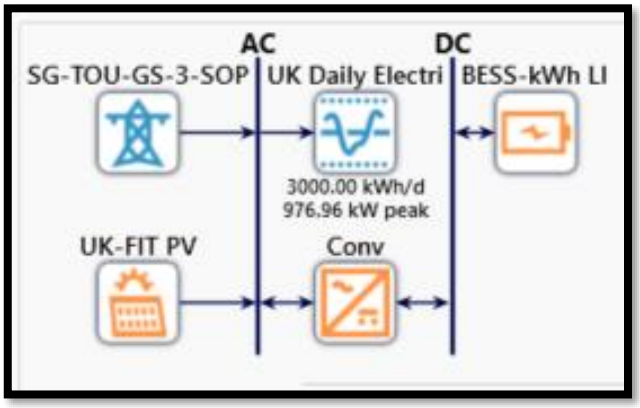



Figure 5. 5 Model A: Simulation Result for Proposed System : Grid Connection, Solar, and Battery storages

Table 11 **Production Summary**

| Component | Production (kWh/yr) | Percent |
|---|---|---|
| **UK FIT PV** | 3,184,667 | 92.3 |
| **Grid Purchases** | 266,600 | 7.72 |
| **Total** | 3,451,267 | 100 |

Table 12 **Consumption Summary**

| Component | Consumption (kWh/yr) | Percent |
|---|---|---|
| **AC Primary Load** | 730,000 | 22.5 |
| **Grid Sales** | 2,513,855 | 77.5 |
| **Total** | 3,243,855 | 100 |

Analysis of the production and consumption summaries and their consequences:

Production Executive Summary Analysis:

The FIT PV system in the United Kingdom is the primary source of energy generation, accounting for 92.3% of total production. This demonstrates a significant reliance on solar photovoltaic panels for electricity production. The contribution from "Grid Purchases" is 7.72%, indicating that grid-purchased electricity supplements the system's energy requirements. This could be due to variables in solar irradiance or a demand that exceeds PV production.

Consumption Executive Summary: The "AC Primary Load" consumes 22.5 percent of the entire amount of electricity. Almost certainly, this burden represents essential or priority loads that must be powered by the generated energy. “Grid Sales" account for a significant portion (77.5%) of total consumption. This suggests that a significant fraction of the electricity consumed by the system is being sold back to the grid, possibly indicating generation in excess of what is required on-site. Considerations Regarding Evaluation and Optimisation: The large percentage of electricity sold back to the grid (77.5%) may indicate that the generation capacity of the system exceeds the demand on-site. This excess energy may be monetized through feed-in tariffs or other mechanisms, thereby generating additional revenue. While the UK FIT PV system is a significant contributor, there may be opportunities to optimise its performance, such as enhancing solar panel efficiency and maintenance, or investigating energy storage solutions to utilise excess daytime generation during nighttime or low-sunlight hours.

To further decrease dependence on grid purchases and increase self-consumption, energy efficiency measures such as optimising loads, instituting demand-side management, and incorporating energy storage systems can be investigated. If grid sales continue to outpace consumption, it may be advantageous to assess whether adjusting system sizing or energy management strategies would help achieve a better generation-consumption balance.

**Overall Consequences:**

The production and consumption summaries underscore the significance of the UK FIT PV system as the primary source of energy and the potential for revenue generation through the sale of excess energy to the grid. Significant grid sales and reliance on grid purchases indicate opportunities to improve system self-sufficiency, efficiency, and cost-effectiveness via strategic adjustments and optimisations.

In conclusion, a thorough analysis of production and consumption data can guide decisions aimed at maximising energy self-sufficiency, optimising financial benefits, and minimising environmental impact within the context of the microgrid system.

### 5.5.1 UK FIT PV output (KW)

UK FIT PV Electrical Summary and Statistics Analysis:

Minimum and Maximum Output: The PV system can run at low levels when there is little sunlight or other causes. Under ideal conditions, the system's highest output is 1,519 kW. PV Penetration: A 436% PV penetration means the PV system's installed capacity exceeds the average load demand. This may be useful for selling excess energy to the grid or storing it. The PV system operates for 4,391 hours per year. This matches the system's solar energy generation during daylight hours. The levelized cost of £0.0649 per kWh shows the average cost of producing power over the system's lifetime. This number assesses PV system economic viability and cost-effectiveness.

Rated capacity: The PV system's maximum output under optimum conditions is 1,386 kW. System sizing and energy generation estimation depend on it.The PV system operates at around

25% of its rated capacity, according to the capacity factor of 26.2%. This value depends on shade, weather, and system design. The system's average daily performance is 364 kW and 8,725 kWh/day. This data helps measure the system's daily energy contribution.

Total Production: The PV system generates 3,184,667 kWh/yr. It's crucial for assessing the system's energy supply impact. The UK FIT PV system is a vital energy source with many operational hours and high production. Optimising its performance and integrating it with other system components could boost the microgrid's efficiency and sustainability.

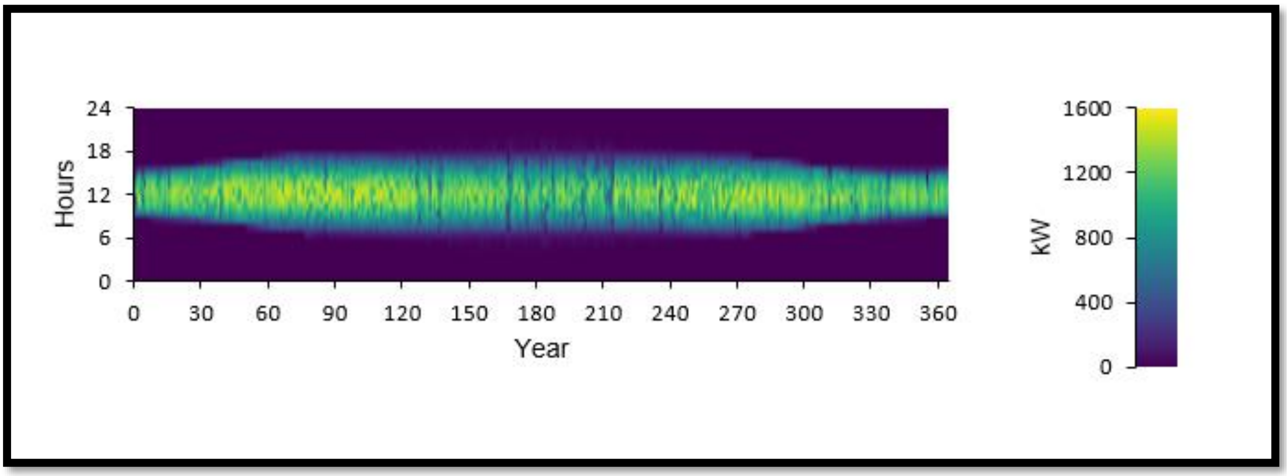



Figure 5. 6UK FIT PV output (KW)

Table 13 Compare Economics

| Metric | Value |
|---|---|
| **Present Worth (£)** | £1,156,125 |
| **Annual worth (£/yr)** | £89,431 |
| **Return on investment(%)** | 7.1 |
| **Internal rate of return (%)** | 10.1 |
| **Simple payback (yr)** | 9.12 |
| **Discounted payback (yr)** | 13.18 |

The chart in Fig 5.7 provides a summary of your estimated annual savings across the following categories:

- Demand: savings from reduced demand charge
- Energy: Decreased consumption and self-consumption
- O&M: Costs for operation and maintenance of the proposed components
- Cost to replace proposed system components over the lifetime of the undertaking

Total: The total annualised savings of the proposed system

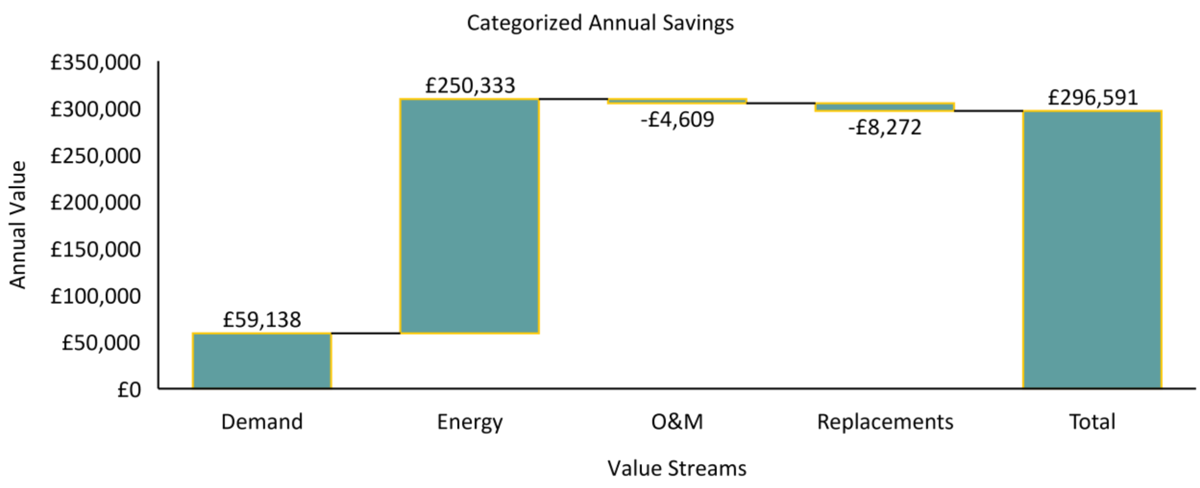



Figure 5. 7The total annualised savings of the proposed system

Your monthly utility bill savings by month

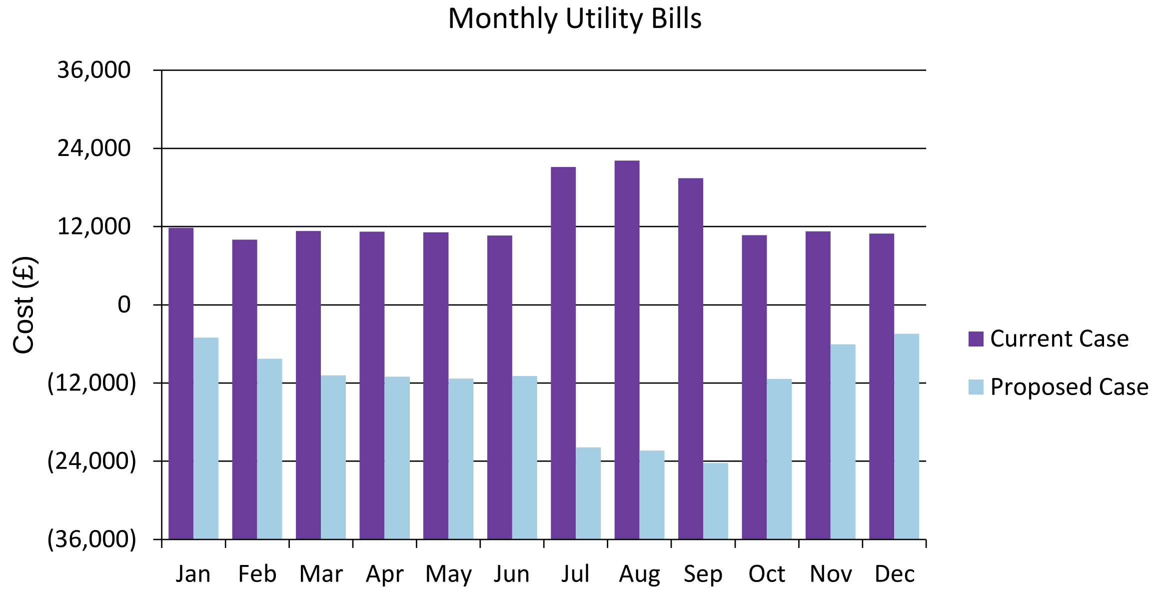



Figure 5. 8 Your monthly utility bill savings by month

Additional examination conducted with the specified economic metrics:

## 5.6 Comparative Analysis of the Proposed System and Base System – Model A

A comparison between the Base System and the Proposed System for Manchester, UK's electric needs:

**Base System**:

The electricity requirements are met exclusively through a utility connection. The annual utility bill totals 161,762 pounds. 61% (£98,560) of the overall utility account is comprised of demand charges.

**Proposed System:**

The proposed system consists of: Adding 1,386 kW of PV (photovoltaic solar panels) capacity.

Integrating 253 kWh of battery energy storage capacity. Among the advantages of the proposed system are:

An annual utility bill reduction to -£147,709, indicating a substantial surplus of generated energy. A repayment period of 9.12 years, representing the time required to recoup the initial investment. A positive Net Present Value (NPV) of £1,16 million, represents the present value of all future cash flows over the lifespan of the system. A Return on Investment (ROI) of 7.07 % indicates a positive return on capital invested. A 10.1% Internal Rate of Return (IRR) indicates an attractive annualised return on investment over time. Annualised savings of £296,591, demonstrating the system's ongoing financial benefits.

**Comparison and Major Learnings**

Financial Advantages:

In terms of financial benefits, the proposed system outperforms the baseline system, with a projected utility bill surplus, positive NPV, attractive ROI, and attractive IRR.

Investment and Return:

The proposed system requires an investment of £2.68 million, with a return period of 9.12 years. Investment and return information for the foundation system is not provided.

Investments and Returns:

Annual savings of £296,591 exemplify the ongoing financial benefits of the proposed system over the baseline system. The financial appeal of the proposed system is enhanced by positive NPV, ROI, and IRR returns.

Energy Independence and Environmental Sustainability:

The energy surplus generated by the proposed system demonstrates its energy independence. The integration of PV and battery storage reduces carbon emissions and is consistent with sustainability objectives.

Considerations in Making a Decision:

The proposed system presents a compelling argument from both a financial and environmental perspective. The computed financial metrics indicate that the proposed investment is feasible and has the potential to generate substantial returns over time. Energy resilience and stability are improved by the addition of energy storage via batteries.

In summary:

the Proposed System offers a highly prospective solution with its potential for significant energy savings, financial gains, and positive environmental contributions. The combination of photovoltaic (PV) capacity and battery storage makes the proposed system feasible and enticing, as it provides both economic benefits and a step towards sustainable energy practises.

## 5.7 Model B - Grid Connection, Solar, EV and Battery storages

Model B integrates solar panels, EV, battery storage with the grid.

(UK FIT PV): Photovoltaic (PV) System

A photovoltaic (PV) system is made up of solar panels that convert sunlight to electricity. The measure of 1,386 kW indicates the solar panels' capacity to generate electricity under optimal conditions. FIT (Feed-in Tariff) in the United Kingdom presumably refers to a government incentive programme that compensates users for the renewable energy they generate and feed back into the grid.

Electric Vehicle (EV)

The 12.6 charging sessions per day are supplied through 4 chargers, each capable of providing 12.0 kW maximum power output. An average of 37.4 potential users per day left without charging because all chargers were occupied when they arrived

Battery Storage System (kWh Li-ion Generic):

The excess electricity generated by solar panels is stored in batteries for later use. The term "Generic kWh Li-Ion" refers to a lithium-ion battery. The presence of 253 strings indicates a substantial quantity of storage capacity, given that each string may consist of multiple batteries connected in series or parallel.

System Converter (Large, Free, Generic Converter):

A system converter, also known as an inverter or converter, transforms the direct current (DC) electricity generated by solar panels or stored in batteries into alternating current (AC) that is compatible with the electrical infrastructure or for local consumption. The large size of 9,999,999 kW may indicate that the converter is capable of handling a significant quantity of energy.

Utility (Time of Use, Electric Vehicle, Demand Metered):

The utility pricing model incorporates both "General" and "Time of Use" pricing variations. However, "Electric Vehicle" suggests that fueling EVs may involve unique pricing considerations. The term "Demand Metered" still implies charges based on peak demand.

Table 14 System Architecture- Model B

| Component | Name | Size | Unit |
|---|---|---|---|
| **PV** | UK FIT PV | 15,063 | kW |
| **EV** | EV | 2.0 | |
| **Storage** | Generic kWh Li-Ion | 14,334 | strings |
| **System converter** | Generic large, free converter | 9,999,999 | kW |
| **Dispatch strategy** | HOMER Peak Shaving | | |
| **Utility** | General - Time of Use, Electric Vehicle, Demand Metered | | |

Base system : Grid _ Connection

Proposed System : Grid Connection, Solar, EV and Battery storages

## 5.8 Simulation Result of Model B

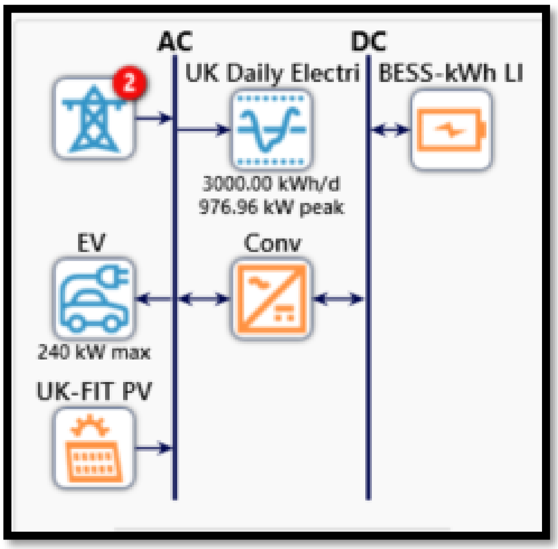



Figure 5. 9Model B: Simulation Result for Proposed System : Grid Connection, Solar, EV and Battery storages

Table 15 Compare Economics – Model B

| Metric | Value |
|---|---|
| **Present Worth (£)** | £1,156,125 |
| **Annual worth (£/yr)** | £89,431 |
| **Return on investment(%)** | 7.1 |
| **Internal rate of return (%)** | 10.1 |
| **Simple payback (yr)** | 9.12 |
| **Discounted payback (yr)** | 13.18 |

The economic metrics of Model B are as follows:

Table 12 compare economics model B: present worth (£1,156,125) is a financial statistic that signifies the comprehensive value of the investment across its whole lifespan, taking into account the concept of the time value of money. In the given scenario, it can be observed that the present worth exhibits a positive value, so signifying that the investment is anticipated to yield a greater value in comparison to its associated expenditures. The observed outcome indicates a favourable indication for Model B. The annual worth, denoted in pounds per year (£/yr), signifies the net financial gain or loss per annum that is linked to the investment. In the present scenario, the outcome is favourable, as it suggests that Model B is anticipated to yield a net financial gain of £89,431 year. The return on investment (ROI) of 7.1% represents the profitability of an investment, quantified as a percentage. A return on investment (ROI) of 7.1% indicates that Model B is projected to yield a return of 7.1 pence for each pound invested. Typically, this return on investment (ROI) is deemed acceptable for a wide range of investment opportunities. The Internal Rate of Return (IRR) is calculated to be 10.1%. The internal rate of return (IRR) refers to the annualised effective compounded return rate that can be achieved on invested capital. An internal rate of return (IRR) of 10.1% suggests that the investment is projected to generate an annual return exceeding 10.1%. This is frequently regarded as a favourable rate of return and surpasses the anticipated return of numerous other risk-averse investments. The simple payback period, denoted as 9.12 years, represents the duration required for the cumulative cash flows to reach parity with the initial investment. Based on the given scenario, the estimated duration for the initial investment in Model B to be recuperated is roughly 9.12 years.The discounted payback period, which accounts for the time worth of money by considering the present value of future cash flows, is calculated to be 13.18 years. Based on discounted cash flow analysis, the projected time required to recoup the initial investment is estimated to be roughly 13.18 years.

Finally, it can be inferred that Model B demonstrates financial feasibility as an investment, as evidenced by its favourable present worth, positive yearly worth, reasonable return on investment (ROI) and internal rate of return (IRR), and very modest payback times. Based on the indicators provided, it can be inferred that the investment in Model B is expected to yield economic benefits during its lifecycle. Nevertheless, it is imperative to take into account the investor's environment and level of risk tolerance when doing the evaluation.

### 5.8.1 EV CHARGING LOAD

The annual energy consumption of this EV depot is 239,953 kWh and the peak load is 48 kW.

Table 16 EV Charging Load

| | |
|---|---|
| Annual Energy Served | 240 MWh |
| Peak Load | 48.0 kW |
| Energy per Session | 52.1 kWh |
| Charging Sessions per Day | 12.6 |
| Charging Sessions per Year | 4,609 |
| Average Missed Sessions per Day | 37.4 |
| Utilization Factor | 57.1 % |

The 12.6 charging sessions per day are supplied through 4 chargers, each capable of providing 12.0 kW maximum power output. An average of 37.4 potential users per day left without charging because all chargers were occupied when they arrived.

The electric vehicles served by this depot have the following charging characteristics:

Table 17 Type of EV

| Name | Percentage of EV Population | Maximum Charging Power per EV | Average Charging Duration |
|---|---|---|---|
| SUV EV | 30.0 % | 150 kW | 260 min |
| Small EV | 70.0 % | 50.0 kW | 260 min |

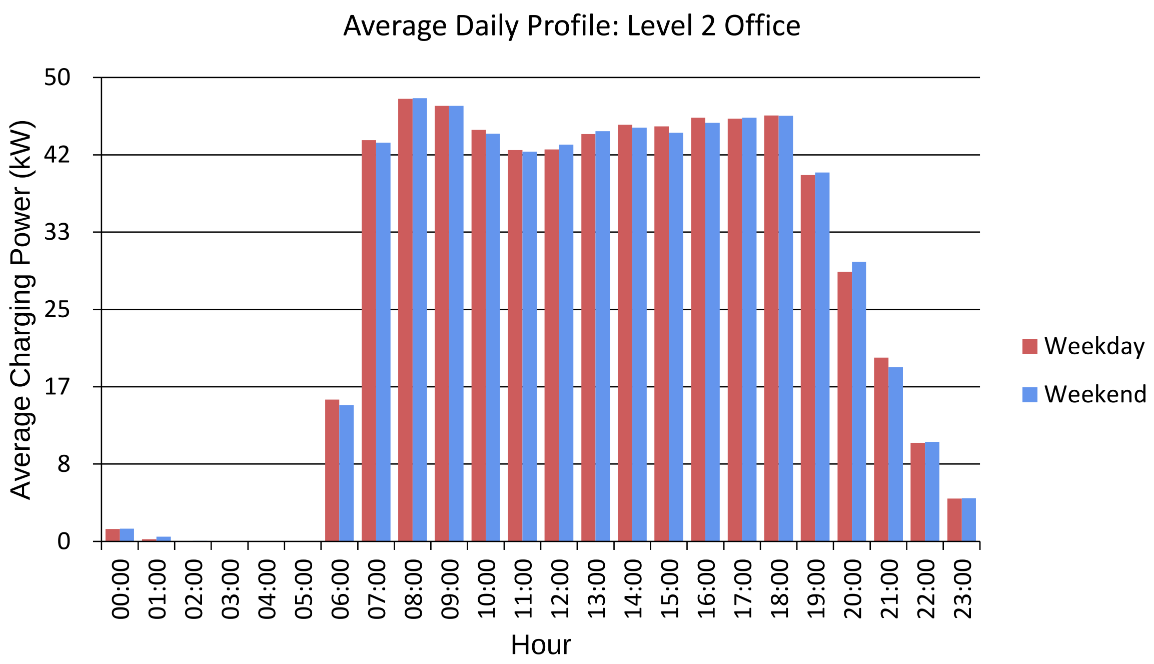



Figure 5. 10EV Load Served

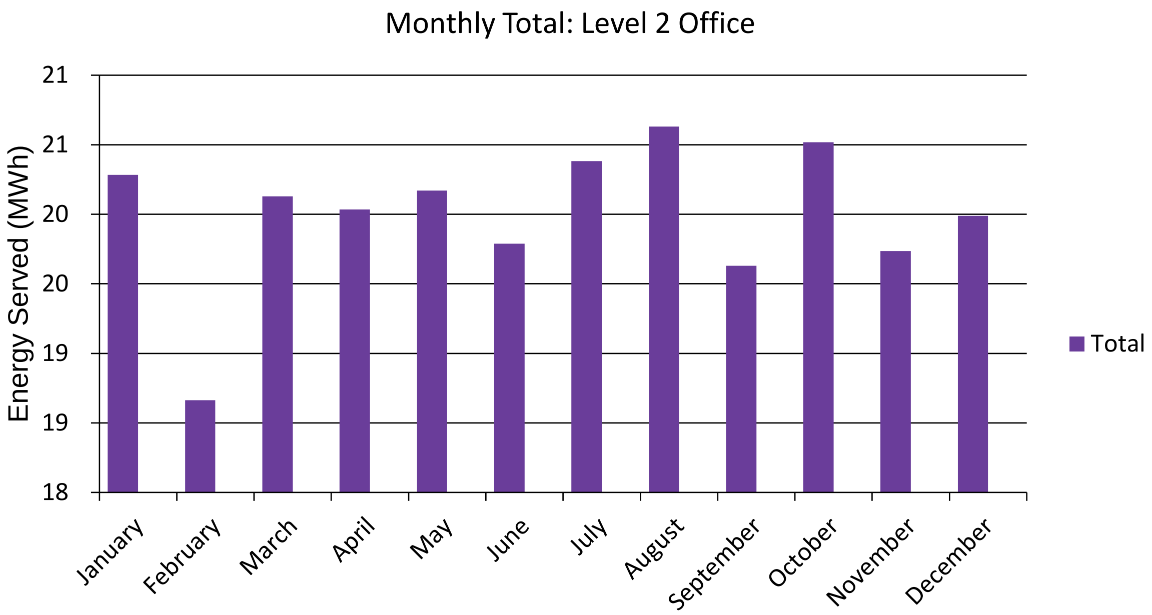
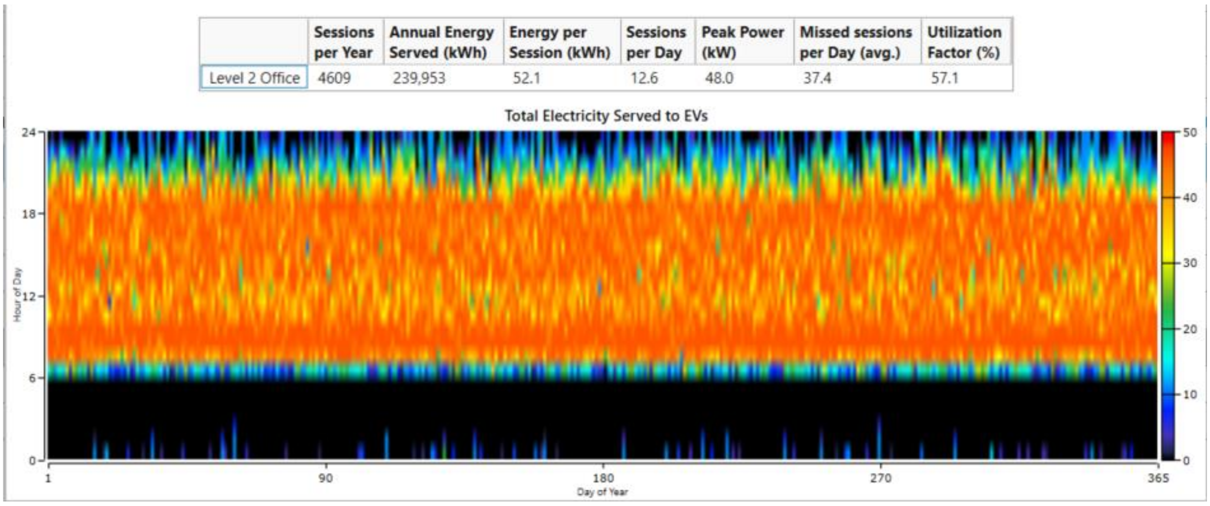



Figure 5. 11 Monthly EV energy Total



| | Sessions per Year | Annual Energy Served (kWh) | Energy per Session (kWh) | Sessions per Day | Peak Power (kW) | Missed sessions per Day (avg.) | Utilization Factor (%) |
|---|---|---|---|---|---|---|---|
| Level 2 Office | 4609 | 239,953 | 52.1 | 12.6 | 48.0 | 37.4 | 57.1 |



Figure 5. 12 Total Electricity serve to EVs

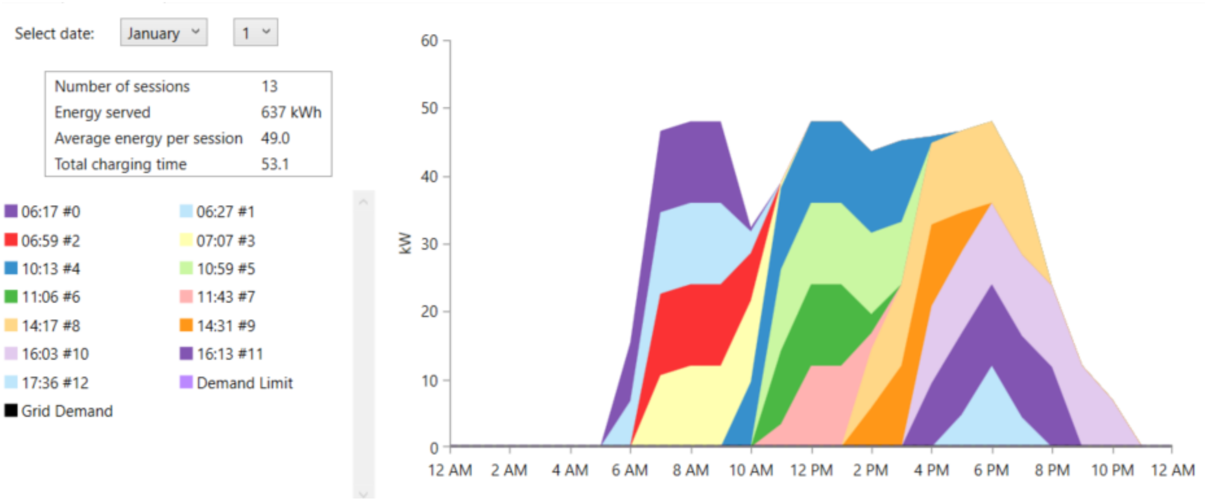



Figure 5. 13 EV Daily profile

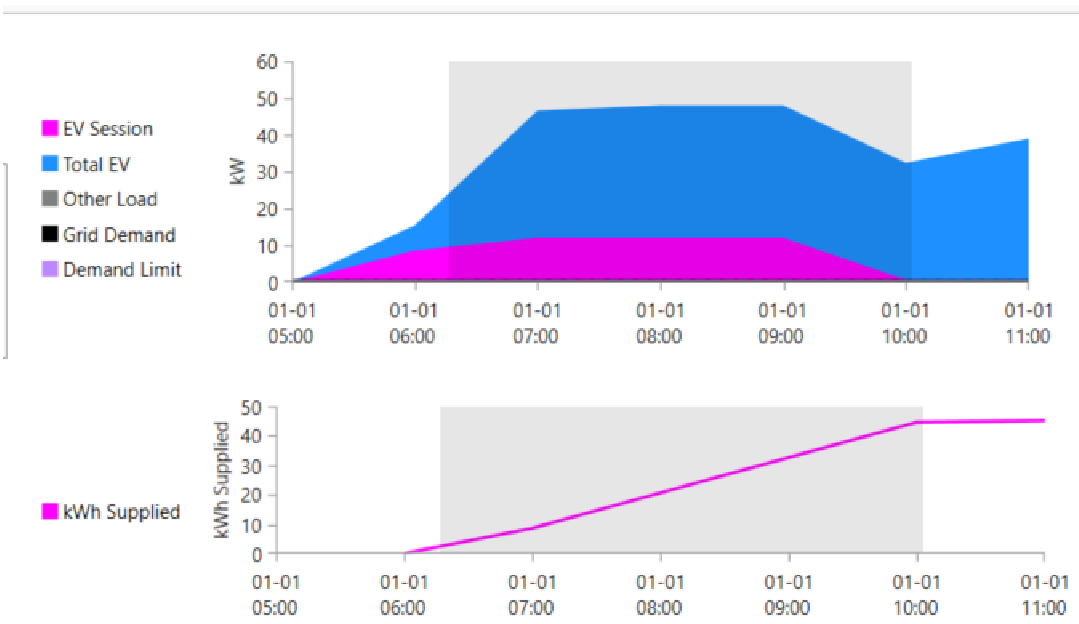



Figure 5. 14 Single Session- EV

The figure 5.15 provides a summary of your estimated annual savings across the following categories:

- Demand: savings from reduced demand charge
- Energy: Decreased consumption and self-consumption
- O&M: Costs for operation and maintenance of the proposed components
- Cost to replace proposed system components over the lifetime of the undertaking

Total: The total annualised savings of the proposed system

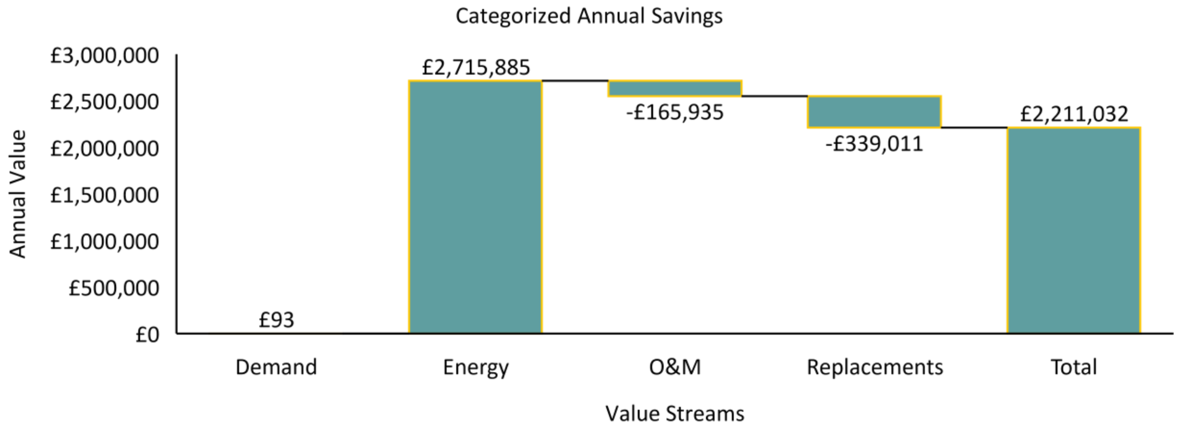



Figure 5. 15 Categorized Annual savings

## 5.9 Comparative Analysis of the Proposed System and Base System – Model B

In this analysis, we will examine the economic aspects of the Base System and the Proposed System in Model B, taking into account the recently presented data.

The Base System, often known as Model B, is being referred to. The electricity requirements for the area of Manchester, UK are fulfilled via a grid connection. The yearly utility expenditure totals £121,689. The demand charges account for 1.2% (£1,460) of the overall power bill. The proposed system, referred to as Model B, is being presented for consideration.

The system under consideration encompasses:

The installation of an additional 15,063 kW of photovoltaic (PV) capacity, specifically referring to solar panels that convert sunlight into electricity, is being considered. The implementation of a battery capacity of 14,334 kWh is being considered for the purpose of energy storage.

The advantages of the suggested system encompass:

The annual power bill has experienced a remarkable drop, reaching a negative value of £2.59 million, which suggests a noteworthy surplus of generated energy. The payback period, which denotes the duration necessary to recover the initial investment, is calculated to be 8.92 years.

The Net Present number (NPV) is calculated to be £5.83 million, indicating a favourable outcome. This number represents the present worth of all anticipated cash inflows and outflows during the system's duration. The Return on Investment (ROI) of 5.69% demonstrates a favourable outcome in terms of the return achieved on the capital that was invested. The Internal Rate of Return (IRR) is calculated to be 8.53%, indicating a favourable annualised return on investment over a period of time. The suggested approach demonstrates a consistent financial advantage through annualised savings up to £2.21 million.

The comparison in Model B is as follows:

The Reduction of Utility Bills: An Analysis. The amount indicated on the utility bill is £121,689.The utility bill exhibits a noteworthy reduction of almost £2.59 million, suggesting a considerable surplus resulting from the output of energy surpassing its use. Financial metrics are quantitative measures used to assess the financial performance and health of a company.

The payback period of the Proposed System, which is estimated to be 8.92 years, indicates a suitable duration during which the investment can be recouped. The suggested system exhibits a positive net present value (NPV) of £5.83 million, indicating the possibility for enduring financial advantages. The presence of a positive return on investment (ROI) and an appealing internal rate of return (IRR) suggest that the investment in the proposed system is anticipated to generate advantageous financial outcomes. The suggested system's financial advantages are underscored by the significant annualised savings of £2.21 million.

**The topic of interest pertains to investment and capital.**

The proposed system necessitates a significant capital investment of £22.8 million, which exhibits a comparatively higher value in relation to the Base System.

The Pursuit of Energy Autonomy and Environmental Stewardship: The surplus energy output of the suggested system serves to enhance energy independence and mitigate carbon emissions, so harmonising with the objectives of sustainability.

Factors to Consider in the Decision-Making Process: The proposed approach presents a persuasive financial argument, supported by favourable financial indicators and significant yearly cost reductions. The assessment of the increased capital expenditure required for the proposed system should be conducted in relation to the projected savings and advantages. The proposed system in Model B exhibits considerable promise for achieving cost reductions, decreased electricity expenses, and diminished environmental consequences. Although the initial capital required is considerable, the potential long-term cost reductions in operations and energy consumption render it a compelling option, particularly when taking into account the associated ecological advantages.

## 5.10 Compare Model A and Model B

Table 18 Compare Economics

| Metric | Model A- Value | Model B- Value |
|---|---|---|
| Present Worth (£) | £1,156,125 | £5,825, 138 |
| Annual worth (£/yr) | £89,431 | £450,600 |
| Return on investment(%) | 7.1 | 5.7 |
| Internal rate of return (%) | 10.1 | 8.53 |
| Simple payback (yr) | 9.12 | 8.92 |
| Discounted payback (yr) | 13.18 | 16.0 |

Table 19 Model A – Predicted Electric Bill

| Month | Energy Charge | Energy Purchased | Energy Sold | Demand Charge | Fixed Charge | Total |
|---|---|---|---|---|---|---|
| **Jan** | -£9,705 | 33,546 kWh | 171,282 kWh | £4,230 | £462.59 | -£5,012 |
| **Feb** | -£12,414 | 25,047 kWh | 199,180 kWh | £3,699 | £462.59 | -£8,252 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Mar** | -£15,328 | 24,084 kWh | 243,119 kWh | £4,035 | £462.59 | -£10,830 |
| **Dec** | -£8,349 | 33,942 kWh | 151,055 kWh | £3,457 | £462.59 | -£4,429 |
| **Ann.** | -£192,682 | 266,600 kWh | 2,513,855 kWh | £39,422 | £5,551 | -£147,709 |

Table 20 Model B- Predicted Electric Bill

| Month | Energy Charge | Energy Purchased | Energy Sold | Demand Charge | Fixed Charge | Total |
|---|---|---|---|---|---|---|
| **Jan** | -£90,143 | 13,603 kWh | 2,189,987 kWh | £135.18 | £25,943 | -£64,065 |
| **Feb** | -£116,102 | 12,237 kWh | 2,586,481 kWh | £112.47 | £33,400 | -£82,590 |
| **Mar** | -£198,641 | 13,514 kWh | 3,271,856 kWh | £85.08 | £55,527 | -£143,029 |
| **Dec** | -£87,506 | 14,684 kWh | 1,934,651 kWh | £112.69 | £25,192 | -£62,201 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Ann.** | -£3.64M | 144,699 kWh | 32,959,119 kWh | £1,366 | £1.04M | -£2.59M |

## 5.11 Table 16 and Table 17 Comparison of Predicted Electric Bills – Model A vs Model B

Comparison: Both Model A and Model B demonstrate significant decreases in energy expenses, leading to overall financial benefits.

Model B exhibits significantly greater volatility in energy charges, particularly during specific months such as March, April, and June, leading to more pronounced oscillations in costs.

Model A exhibits a more equitable distribution between energy purchased and energy sold, but Model B demonstrates a significant surplus in the amount of energy sold.

The monthly variation in demand charges is observed in both models. There are observed variances in fixed charges, with Model B exhibiting greater fixed charges. The annual totals for both models have negative values, suggesting significant cost reductions.

The energy charges for both Model A and Model B exhibit negative values consistently over the course of the year. This observation suggests that the systems are producing a surplus of energy relative to their consumption, leading to reductions in energy expenditures. In general, Model A entails a greater quantity of energy being procured and a lesser quantity of energy being sold in comparison to Model B. This suggests that Model A is more dependent on externally sourced electricity from the grid. In contrast, Model B entails an excess of energy that is returned to the grid, so offering the possibility of generating cash through the sale of energy. Considerations: Model B exhibits more pronounced oscillations in energy charge and energy sales, maybe due to greater variability in energy generation and consumption. The negative values seen in both models underscore the potential for cost reduction when compared to conventional utility bills.

Both Model A and Model B demonstrate significant cost reductions when compared to conventional utility bills. On the other hand, Model B has greater diversity in costs, maybe attributable to variations in energy generation, consumption, and pricing frameworks. The overarching conclusion is that both models present the possibility of cost reduction advantages, albeit contingent upon variables such as energy production capacity, consumption patterns, and the consumer's willingness to endure changes in costs.

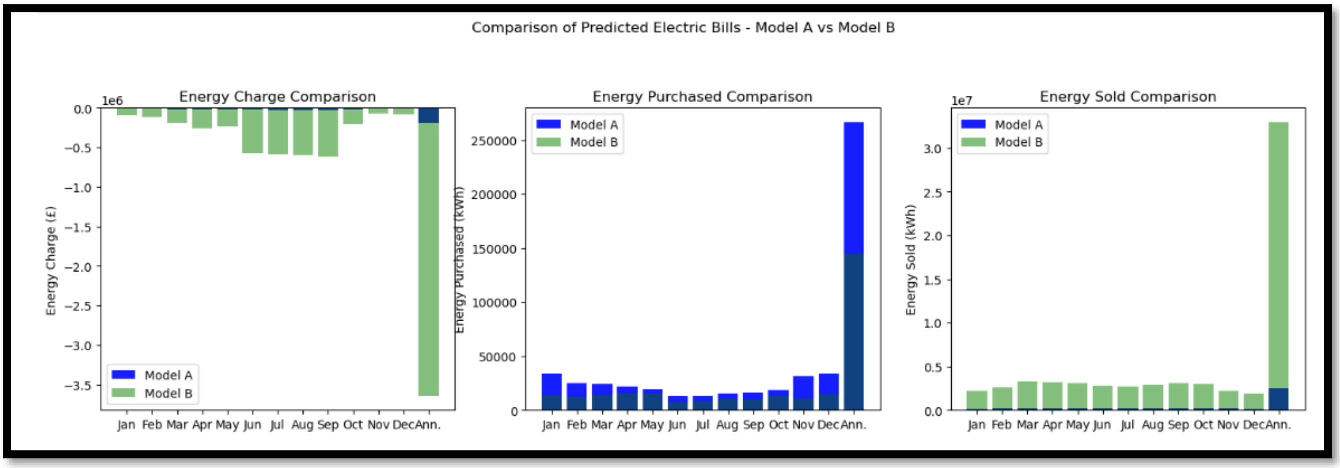



Figure 5. 16Comparison of Predicted Electric Bills – Model A Vs Model B

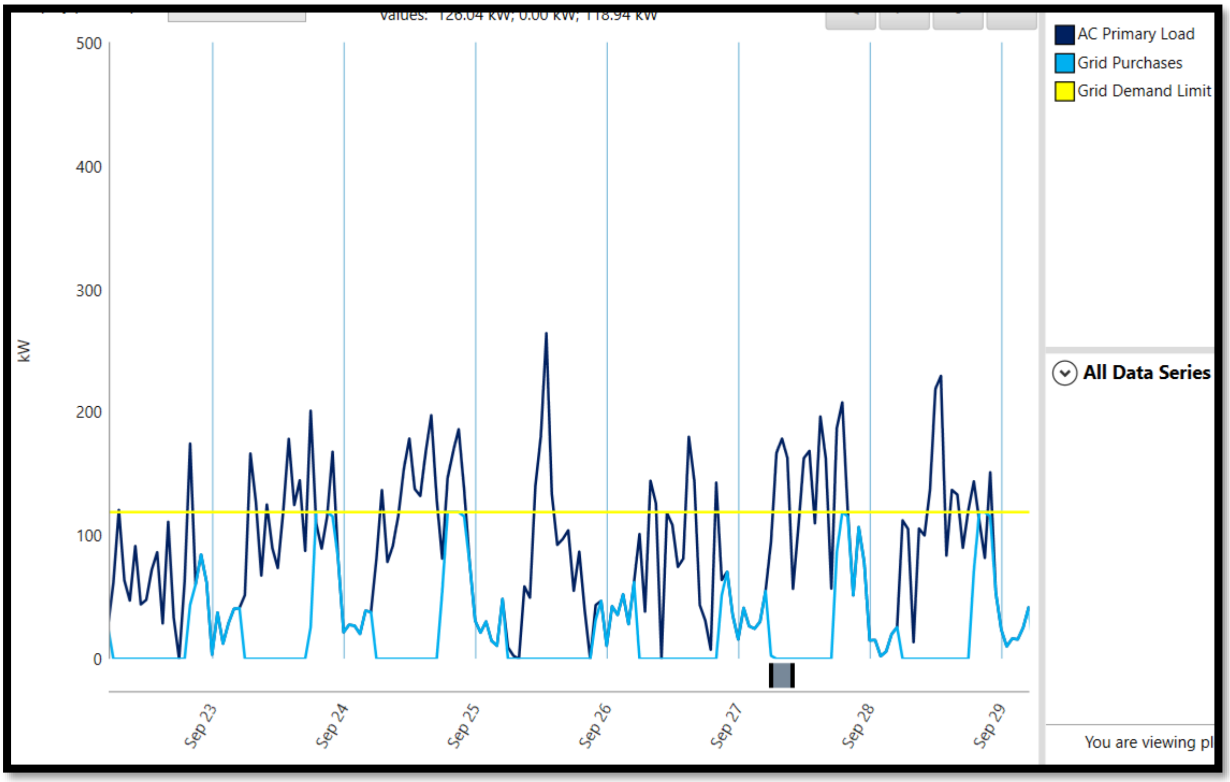



Figure 5. 17 Model A-Hourly Grid and load

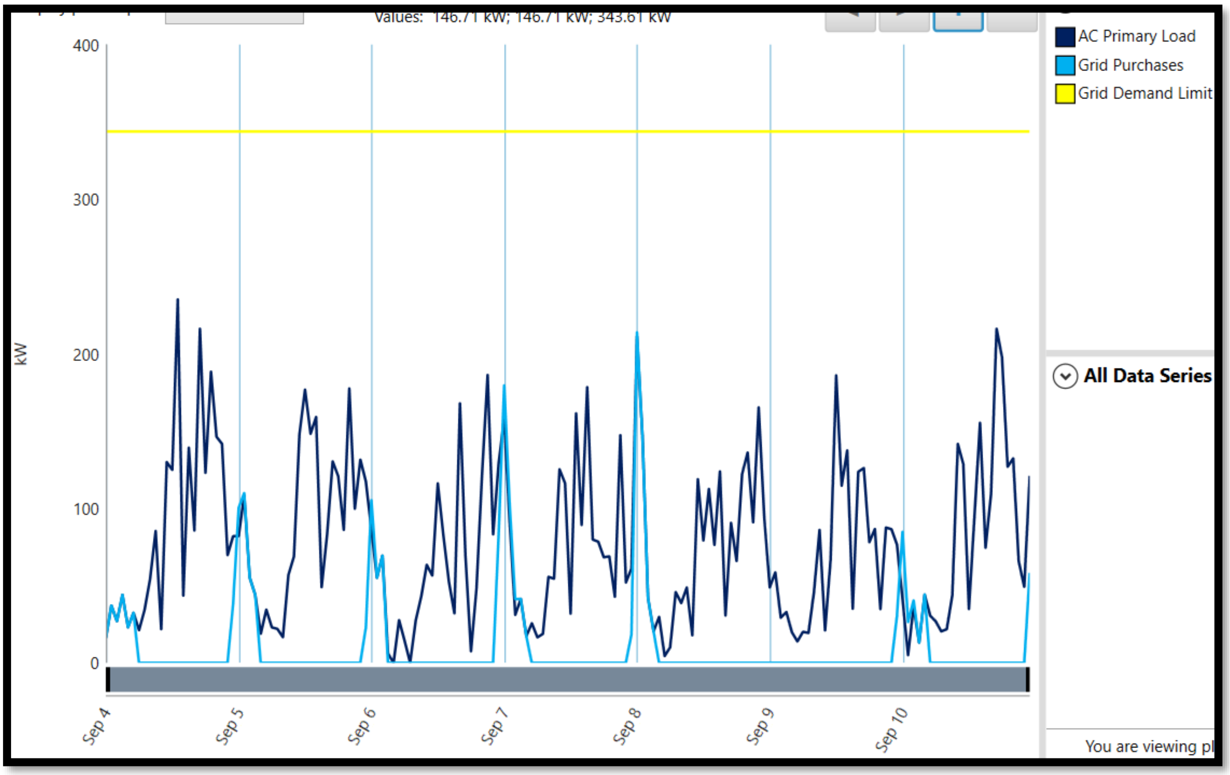



Figure 5. 18 Model B-Hourly Grid and load

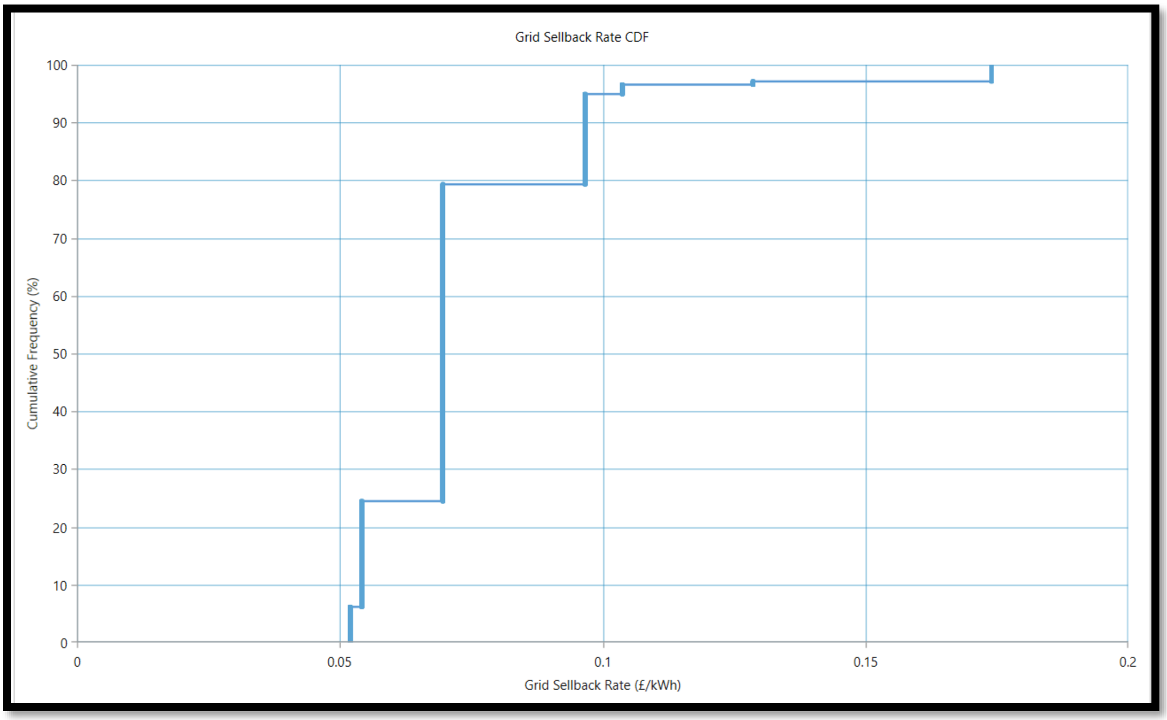



Figure 5. 19 Model A- Grid Sellback Rate

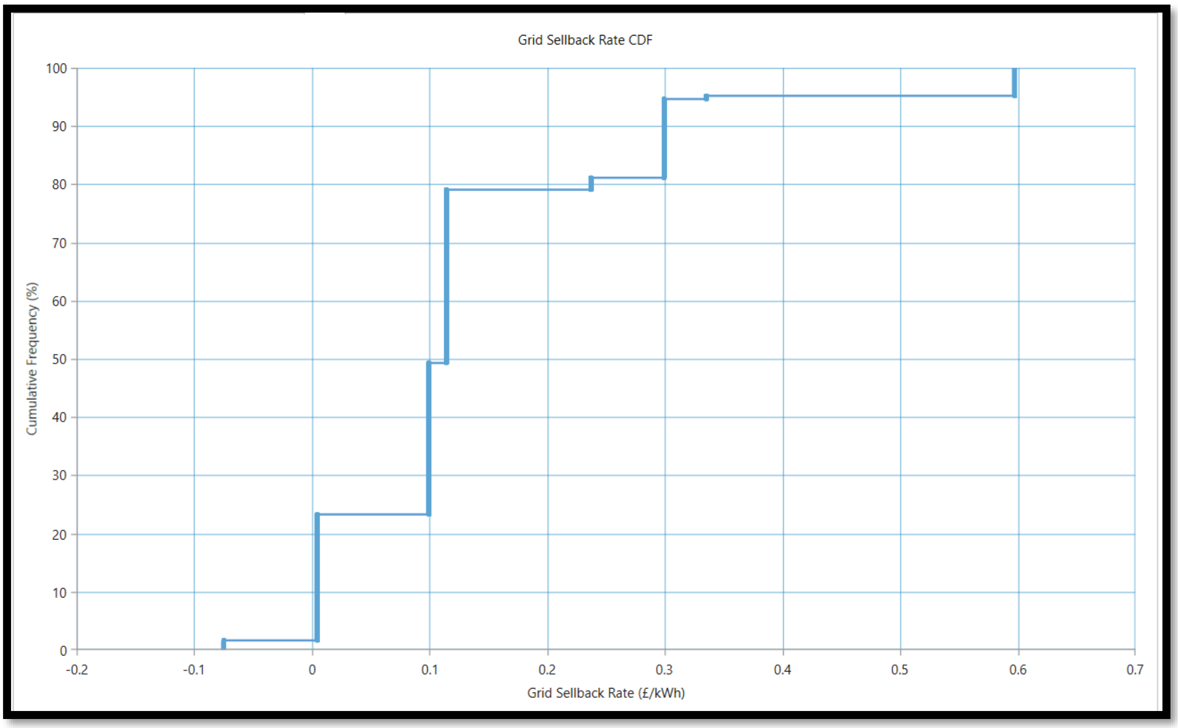



Figure 5. 20 Model B- Grid Sellback Rate

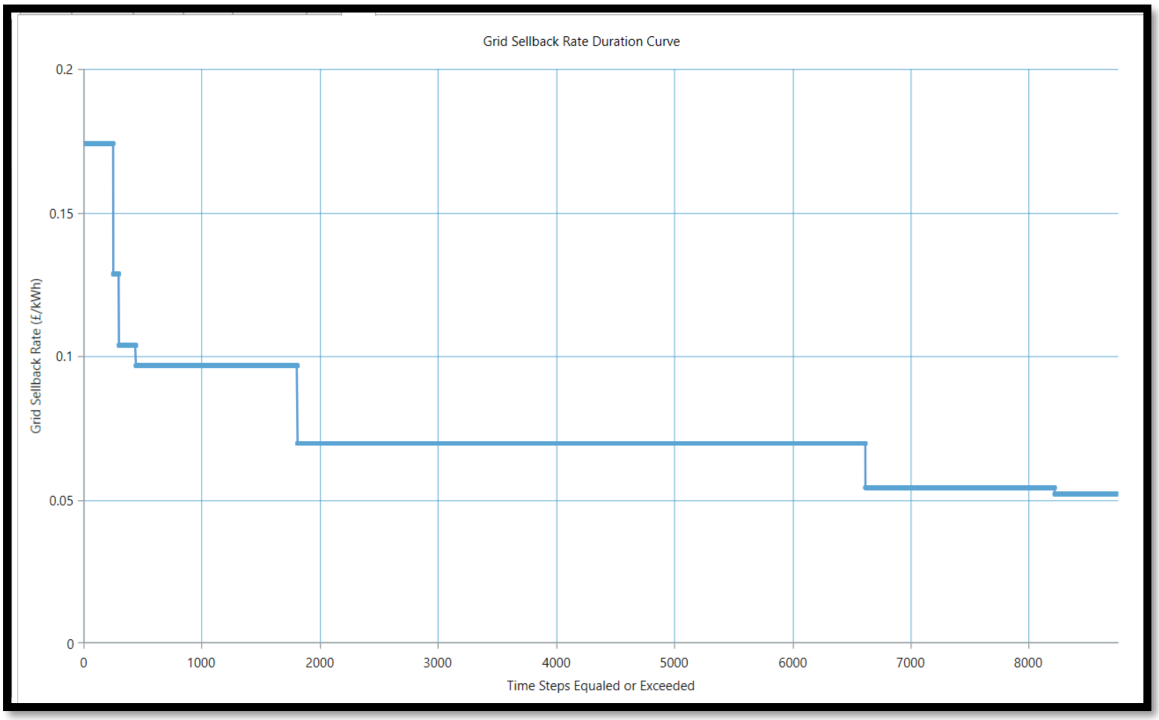



Figure 5. 21 Model A- Grid Sellback rate Duration

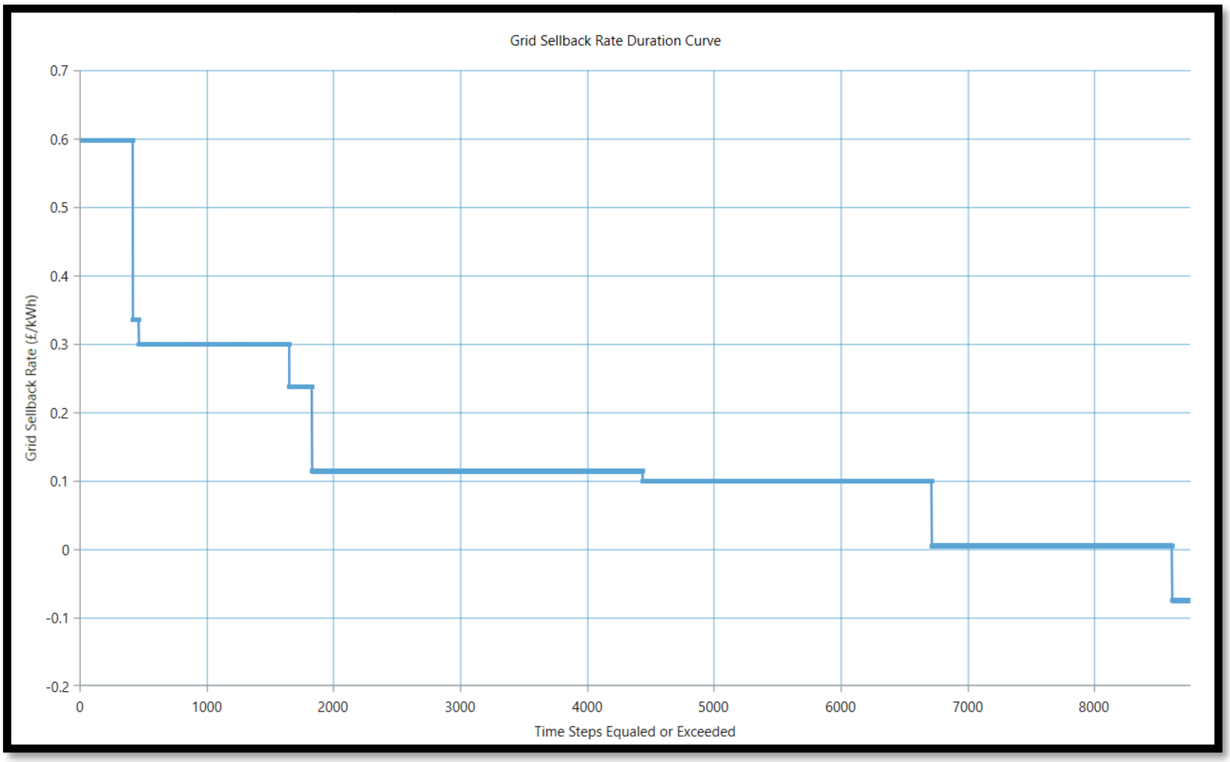



Figure 5. 22 Model B- Grid Sellback rate Duration

Based on the production and consumption components, let's contrast Models A and B's energy summaries:

**Electrical Model A - Summary**

Production Summary

- 3,184,667 kWh/yr (92.3%) of UK FIT PV production
- 266,600 kWh/year (7.72%) of grid purchases
- 3,451,267 kWh produced overall per year (100%)

Consumption summary

- 730,000 kWh per year (22.5%) are consumed by the AC's primary load.
- 2,513,855 kWh/year (77.5%) sold on the grid
- 3,243,855 kWh consumed overall per year (100%)

**Electrical Model B - Summary**

Production Summary

- 34,626,445 kWh/year (99.6%) of UK FIT PV production
- Grid purchases total 144,699 kWh per year (0.416%).
- Production as a whole: 34,771,144 kWh/year (100%)

Consumption summary:

- 730,000 kWh/year (2.15%) of AC primary load consumption
- Sales from the grid: 32,959,119 kWh/year (97.1%).
- Consumption of EV Chargers: 239,953 kWh/yr (0.707%)
- 33,929,072 kWh consumed overall per year (100%)

In this study, we present a comprehensive overview of consumption patterns.

The annual primary load consumption of the AC system is 730,000 kilowatt-hours, which accounts for 2.15% of the total energy usage. The annual sales of electricity from the grid amount to 32,959,119 kilowatt-hours, or 97.1% of the total.The annual consumption of electricity served by the electric vehicle (EV) charger amounts to 239,953 kilowatt-hours, which constitutes 0.707% of the total energy consumption. The annual total consumption of electricity amounts to 33,929,072 kilowatt-hours, representing 100% of the whole consumption.

In this analysis, we will compare and contrast two different approaches to solving the problem at hand. The purpose of this analysis is to compare and contrast Model A and Model B in order to determine their respective strengths and weaknesses. The following is a summary of the production process.

The UK FIT PV production of Model B demonstrates a substantial increase, reaching 34,626,445 kWh/yr (99.6%), in comparison to Model A's production of 3,184,667 kWh/yr (92.3%). This observation suggests that Model B relies significantly more on the UK FIT PV system for its energy generation. Model A exhibits a higher reliance on grid purchases for its output, accounting for 7.72% of its overall production, whilst Model B demonstrates a significantly lower dependence on grid purchases, constituting merely 0.416% of its production.

A Comparative Analysis of Consumption Patterns between Model A and Model B:

A Synopsis Model B exhibits a slightly elevated AC Primary Load consumption of 2.15% in contrast to Model A, which stands at 22.5%. This implies that the AC Primary Load consumption of Model A constitutes a larger proportion of its total consumption. The sales for consumption of Model B (97.1%) are much more in comparison to Model A (77.5%), suggesting that Model B exhibits a higher level of energy sold back to the grid.

Model B further incorporates the energy usage attributed to an electric vehicle charger, which constitutes a mere 0.707% of the overall energy consumption. The graph below Fig 6.23 shows bar plot illustrating the distribution of production components, specifically "UK FIT PV" and "Grid Purchases," for both Model A and Model B. The blue bars correspond to Model A, whereas the green bars correspond to Model B.

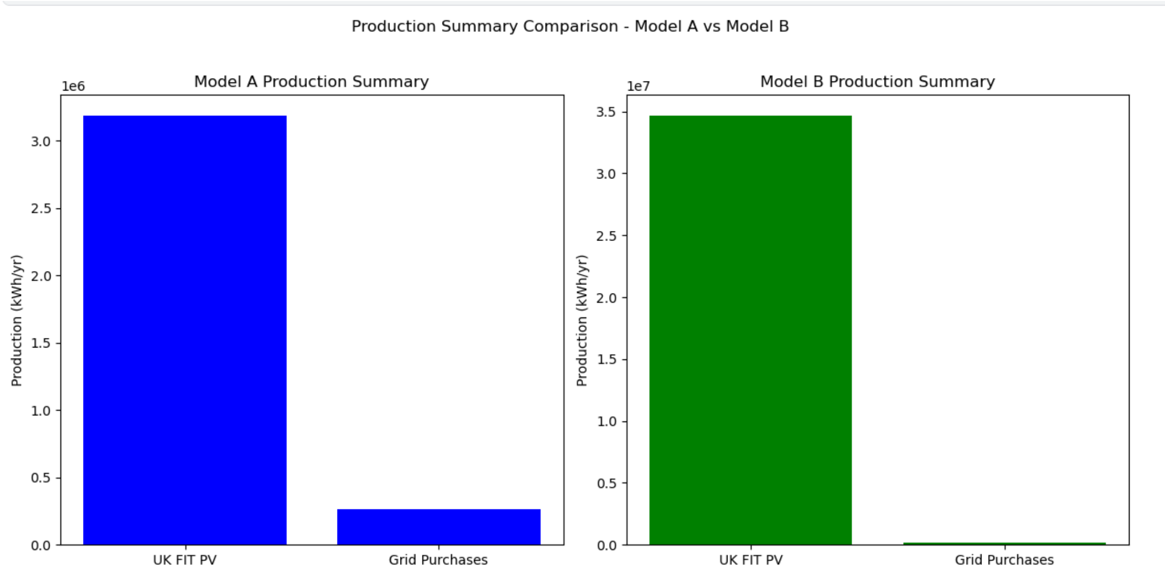



Figure 5. 23 Production Summary Model A vrs Model B

Factors to Consider in the Decision-Making Process:

Model B exhibits a greater level of energy self-sufficiency as a result of its significant generation capacity from the UK Feed-in Tariff (FIT) Photovoltaic (PV) system.

In addition, Model B exhibits a notable surplus of energy, resulting in a higher proportion being sold back to the grid.

The graph in Fig 5.24 below shows bar plot that compares the photovoltaic (PV) production of the UK's Feed-in Tariff (FIT) scheme between two models, namely Model A and Model B. The y-axis represents the statistics for the annual production of photovoltaic systems under the UK Feed-in Tariff scheme, measured in kilowatt-hours per year. The x-axis is utilised to compare the performance of two different models.

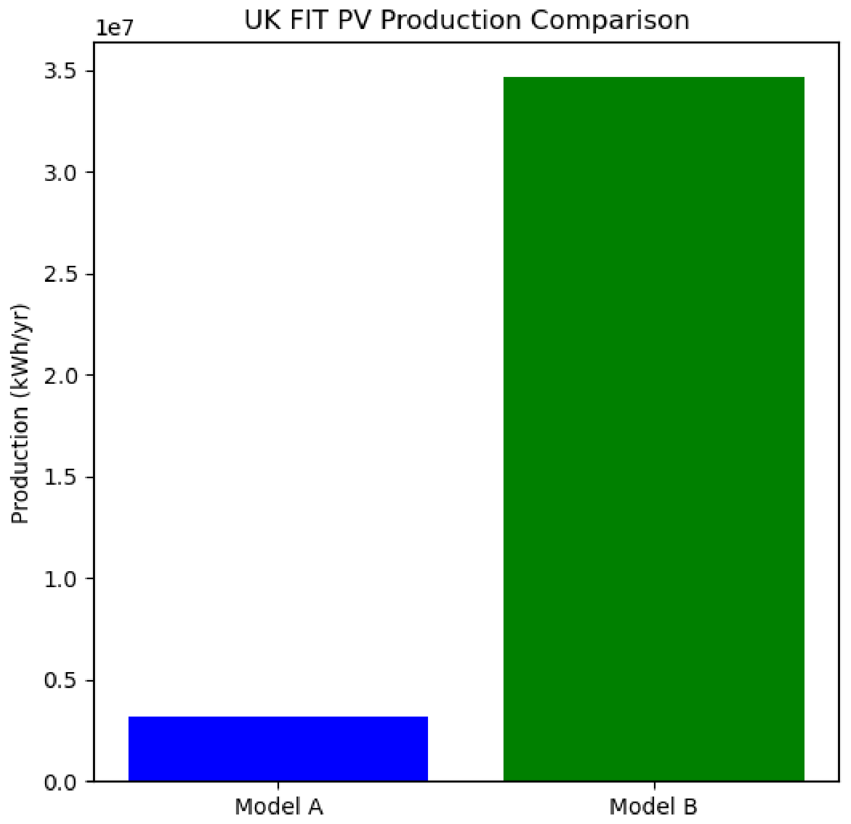



Figure 5. 24 UK FIT PV Production comparison – Model A vs Model B

**Compare model A and B: Utility Bill Saving**

Model A exhibits a greater dependence on grid purchases and a smaller proportion of energy derived by its photovoltaic (PV) system.

Model B demonstrates a higher degree of energy self-sufficiency and a larger excess of energy available for sale in comparison to Model A. This implies that Model B possesses the capacity to create a greater amount of cash through the sale of energy and attain a heightened level of energy self-sufficiency. The selection between the two models may be contingent upon energy production objectives, grid interactions, and the aspiration for energy self-sufficiency.

Comparison: Comparison of Utility Bill Savings between Model A and Model B: • The suggested case for Model A demonstrates substantial annual savings in consumption charges, resulting in a total savings of £250,333. The demand charges for Model A also experience a decrease, leading to an annual cost reduction of £59,138. The fixed rate remains constant in both the base case and the proposed case of Model A. Overall, Model A exhibits significant yearly cost reductions amounting to £309,471.

The suggested instance of Model B demonstrates significant cost reductions in consumption charges, amounting to a total of £3.81 million. The demand charges for Model B also realise a cost reduction of £92.64. However, the fixed rate of Model B experiences a substantial increase as a result of the inclusion of an electric vehicle (EV) and other associated elements. In general, Model B demonstrates a noteworthy annual cost reduction of £2.72 million.

Factors to Consider in the Decision-Making Process:

Both Model A and Model B demonstrate significant reductions in utility bill expenses when compared to their respective baseline scenarios. Model B exhibits notably higher savings, primarily attributed to a more substantial decrease in consumption charges and demand charges, despite a significant increase in its fixed rate.

It can be observed that Model B exhibits greater efficacy in generating savings on utility bills when compared to Model A. This is primarily attributed to the more significant decrease in both consumption charges and demand charges. Nevertheless, it is important to take into account the higher fixed rate of Model B, which is likely attributable to the inclusion of an electric car and other supplementary elements, when assessing the overall financial implications. The selection between the two models would be contingent upon several elements, encompassing energy consumption patterns, price structures, the integration of an electric car, and the intended magnitude of cost reductions.

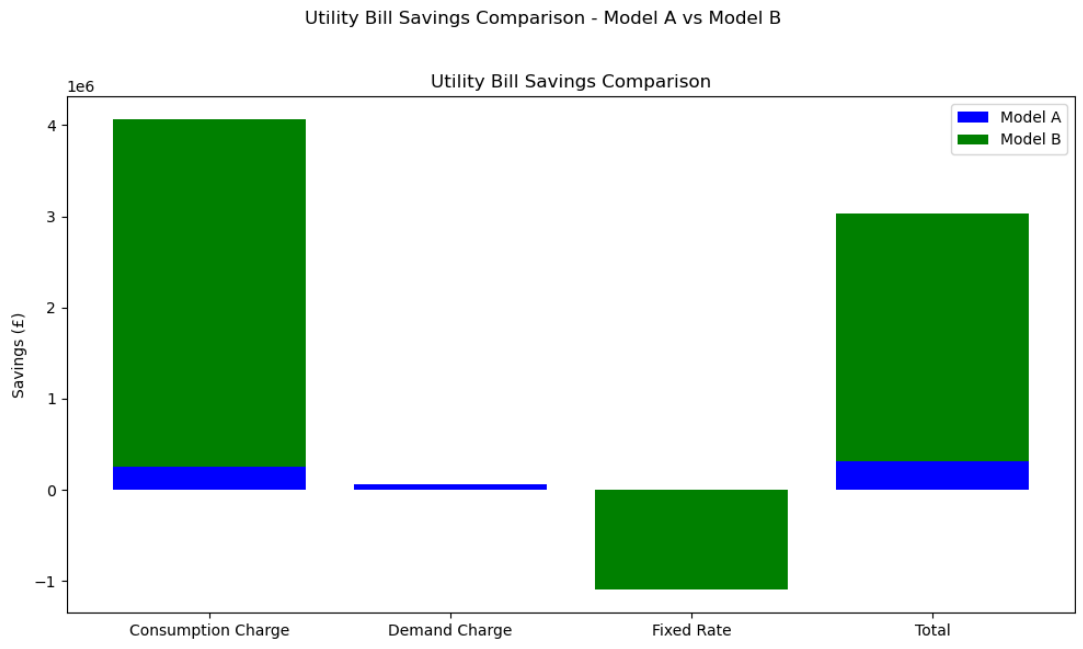



Figure 5. 25 Compare model A and B: Utility Bill Saving

## 5.12 Discussion

**Model A** : **:** Grid-Connection, Solar, and Battery Storage.

The electricity tariff plan you are currently on is the General - Time of Use - Super Off-Peak - Demand Metered

**Model B** : Grid-Connection, Solar,  EV and Battery Storage.

The electricity tariff plan you are currently on is the General - Time of Use, Electric Vehicle, Demand Metered.

Both models demonstrate substantial reductions in consumption expenses, with Model B exhibiting considerably greater savings, surpassing 100%.Model A exhibits significant reductions in demand charges, whereas Model B demonstrates comparatively lesser savings in demand charges that are counterbalanced by an increase in fixed rates resulting from the integration of an electric car. The percentage breakdowns underscore the prevalence of savings from consumption charges in both schemes.

In the case of Model A, the negative percentage associated with demand charge savings suggests that these savings are considerably lower in magnitude compared to the savings achieved through consumption charges. In Model B, the incorporation of an electric vehicle and its corresponding fixed rate augmentation significantly influences the aggregate savings, wherein the fixed rate increase constitutes a substantial proportion of the entirety.

Model A's savings breakdown focuses on the reduction of consumption and demand charges, thereby positioning it as a more predictable option for individuals seeking cost reduction in these specific domains. The cost reductions associated with Model B's increased consumption fee are appealing; however, it is crucial to conduct a comprehensive evaluation of the significant fixed rate rise resulting from the use of an electric car. The selection between the two types is contingent upon several aspects, including the user's energy consumption pattern, the magnitude of demand charges, and the inclination to incorporate an electric vehicle into the energy system.

The percentage breakdowns offer valuable insights on the mix of savings and cost increases associated with each model. Both models prioritise the importance of saving on consumption charges, however, Model B's incorporation of an electric car results in an elevation of the fixed rate. In order to make a well-informed selection that is in line with their aims and priorities, users should evaluate the percentage breakdowns within the framework of their individual energy requirements, consumption habits, and personal preferences.

## 5.13 Summary

Homer Modelling and Optimisation of the P2P Trading Use Case

In this chapter, we look at Homers modelling and optimisation in the context of P2P energy trading. Our main focus is on modelling the distribution of energy resources (DERs) in a P2P system. We investigate DER mathematical models, examine two separate models - Model A (Grid Connection, Solar, and Battery Storages) and Model B (Grid Connection, Solar, EV, and Battery Storages), and show simulation results for both. This chapter contains useful information about the efficiency and effectiveness of various P2P energy trading systems.

Homer Optimisation and Modelling:

The chapter begins by introducing Homer modelling and optimisation strategies. Homer is a powerful simulation and optimisation tool for microgrid and renewable energy systems. It enables us to simulate different energy generating and storage components and optimise their configurations to suit specific goals, such as cost reduction or sustainability.

DER Modelling in Peer-to-Peer Systems:

We investigate the complexities of modelling Distributed Energy Resources (DERs) in the context of peer-to-peer energy trading. Solar panels, batteries, electric vehicles (EVs), and the electrical grid itself are all examples of DERs. It is critical to accurately model these resources in order to optimise energy distribution.

DER Mathematical Models:

We propose mathematical models for the distributed energy resources (DERs) used in our P2P energy trading models. These models capture the behaviour and characteristics of each DER type, such as generating and storage capacity, efficiency, and costs.

Grid Connection, Solar, and Battery Storage Model A:

We go over Model A in detail, which has a grid-connected system with solar panels and battery storage. This model illustrates a typical configuration for home and commercial solar installations that include energy storage capabilities.

Grid Connection, Solar, EV, and Battery Storage in Model B:

Model B expands on Model A by bringing electric vehicles (EVs) into the P2P energy trading ecosystem. This model takes into account the integration of electric vehicle charging and discharging into the energy distribution network.

Simulation Outcomes:

The simulation results for Model A and Model B are shown. These findings include a variety of criteria such as energy efficiency, cost-effectiveness, grid interaction, and environmental impact. The comparison of these models offers insight on the benefits and drawbacks of various DER configurations.

Conclusions and Implications:

The simulation results provide insights, which we address in terms of their relevance for P2P energy trading systems. This covers energy savings, grid stability, user experience, and the role of EVs in improving the whole ecosystem.

Chapter 5 provides the groundwork for future advances and optimisations in peer-to-peer energy trading. The simulation results' insights and lessons learnt pave the way for improving and customising DER configurations to better match the demands of certain users and scenarios.

Finally, Chapter 5 marks a watershed moment in our investigation of peer-to-peer energy trading networks. Homer modelling and optimisation approaches applied to real-world models A and B provide meaningful insights into the design and management of distributed energy resources. These insights will help us improve the efficiency, sustainability, and resilience of peer-to-peer energy trading, resulting in a more decentralised and ecologically sensitive energy landscape.

# CHAPTER 6 Solar Chain Ethereum P2P Designed And Implementation

## 6.1 Introduction

The Six Chapter explores the crucial process of test evaluation in order to assess the efficacy, efficiency, and dependability of the novel solution for sustainable energy: the integration of a Decentralised Blockchain-Based Platform with Renewable Energy Sources and Micro Grid. This integration facilitates energy exchange and trade through the utilisation of Smart Contracts within a P2P Network. The experimental apparatus employed in conducting the tests will be described. The simulation of real-world scenarios necessitates the utilisation of specific hardware, software, and network infrastructure. These components play a crucial role in creating an accurate and immersive simulation environment. The hardware employed in this context refers to the physical devices and equipment utilised to support the simulation. This may include computers, servers, storage devices, and other peripheral devices. In addition to hardware, software is a fundamental component of simulating real-world scenarios. Software applications are employed to model and replicate various aspects of the 'Solar Chain' real world app, such as physics, behaviour, and interactions. These software programmes are designed to accurately simulate the desired scenarios and this section will examine the external elements that were taken into consideration and the measures implemented to ensure consistency throughout the review process.

The use of smart contracts to facilitate P2P commerce and the implementation of various features are also discussed. The implementation of a frontend user simulation that generates virtual consumers and prosumers based on benchmark data. This simulation helps evaluate the efficacy and performance of the platform in various scenarios. An experiment is conducted using technologies such as Node.js and web3.js API to access the Ethereum Virtual Machine on a testbed. This enables testing and evaluation of the platform's functionality and efficacy in the real world.

***SolarChain*** P2P platform can be access in this URL Link***: http://thesolarchain.co.uk/***

## 6.2 Designed and implemented Blockchain-Based platform for Peer-to-Peer Energy Trading

By the end of this chapter, it will be established that some data, in addition to the exchange of goods that takes place as planned. These are regarded as the primary features of the code that demonstrate a secure system for its users and an effective market as well. In this section, we describe the proof of concept in technical details, including requirements, scenarios, architecture design decisions and outcomes. The designed and implementation included the following features:

### 6.2.1 P2P Flowchart

Initializes and starts monitoring energy surplus from users with solar panels.

- ✓ Detect Energy Surplus: The system detects if a user (home with solar panels or EV owner) has an excess of energy that can be sold.
- ✓ User Chooses to Participate in Trading: The user decides to participate in the energy trading process.
- ✓ Retrieve Energy Price Data: The system gathers data on current energy prices from the grid and other relevant sources.
- ✓ User Specifies Trading Parameters: The user specifies the amount of energy they want to sell, trading duration, and other relevant parameters.
- ✓ Create Sell Offer: Based on the user's parameters, the system creates a sell offer listing the available energy for trading.
- ✓ Submit Sell Offer: The user submits the sell offer to the P2P trading platform.
- ✓ Offer Validation and Confirmation: The platform validates the sell offer for accuracy and completeness.
- ✓ Offer Listed on P2P Trading Platform: The sell offer is listed on the P2P trading platform for potential buyers to see.
- ✓ Buyers Place Bids: Interested buyers place bids for purchasing the available energy.
- ✓ Monitor Bids and Choose Highest Bid: The system monitors the bids and selects the highest bid among the offers.
- ✓ Accept Highest Bid: The highest bid is accepted by the seller, indicating the successful trade.

- ✓ Match Sellers and Buyers: The system matches the seller with the chosen buyer.
- ✓ Confirm Trade and Calculate Transaction Details: The system confirms the trade and calculates transaction details, including energy exchanged, price, and other relevant information.
- ✓ Update Energy Balances: The energy balances of both the seller and the buyer are updated to reflect the trade.
- ✓ Generate Transaction : A transaction is generated containing all trade details.
- ✓ Execute Payment: Payment is executed, transferring funds from the buyer to the seller.
- ✓ Notify Users about Trade Completion: Both the buyer and the seller are notified about the successful completion of the trade.
- ✓ End: The trading process ends.

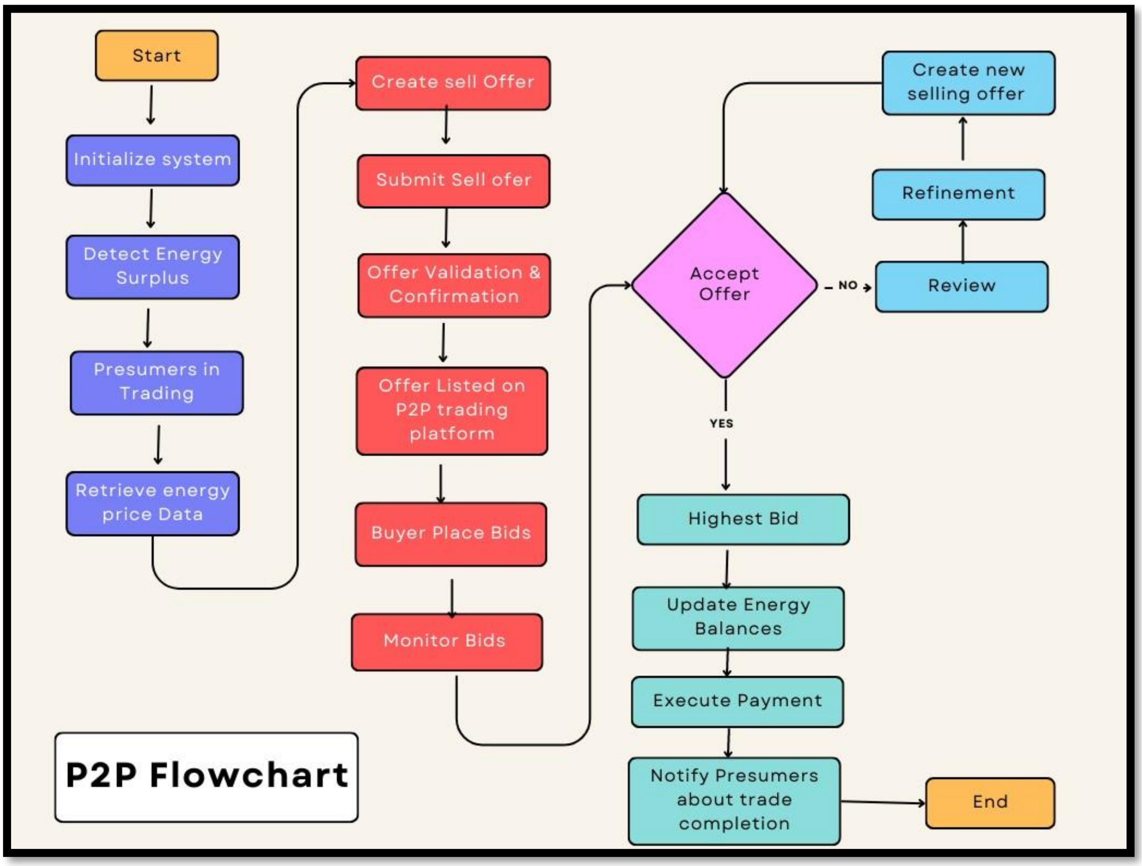



Figure 6. 1 Process flow diagram for p2p proposed system

### 6.2.2 Users/ Participants

Homeowners who have solar PV systems, electric vehicles (EVs), and smart grids are the model's participants. Solar PV-equipped homeowners can produce their own electricity and sell it to other model participants. EVs have the ability to store energy and release it back into the grid. Energy supply and demand may be balanced with the use of smart grids.

```
class EV:
    def __init__(self, ev_type, ev_serial, create_unit, consume_unit, char
        self.ev_type = ev_type
        self.ev_serial = ev_serial
        self.create_unit = create_unit
        self.consume_unit = consume_unit
        self.charging_unit = charging_unit
        self.capacity = capacity
        self.driving_range = driving_range


class HomeWithSolarPV:
    def __init__(self, solar_type, solar_serial, generation_unit, consume_
        self.solar_type = solar_type
        self.solar_serial = solar_serial
        self.generation_unit = generation_unit
        self.consume_unit = consume_unit
        self.charging_unit = charging_unit
        self.capacity = capacity
        self.excess_capacity = excess_capacity
```

Figure 6. 2 The Registration details of EV and Home with solar PV

- Homer Owners with solar on Roof
- Electric Vehicle (EV)- Vehicle to Everything (V2X)- Direct Transaction
- National Grid

### 6.2.3 Home Loads

This research will factor different type of houses such as homer owners with solar, Home without solar and EV parking stations. For the current study, it is critical that the household load profile be unique and related to the types of houses. Real data from households will be use in this research.

### 6.2.4 EV Charging System

An EV charging station or a conventional charger can be used to charge the EV's energy. This method is shown as an optional option in the project, and you can spend the appropriate amount to recharge your energy if you desire.

The implementation is described in detail, along with state diagrams and core procedures.

| Participants | Transactions of asset |
| --- | --- |

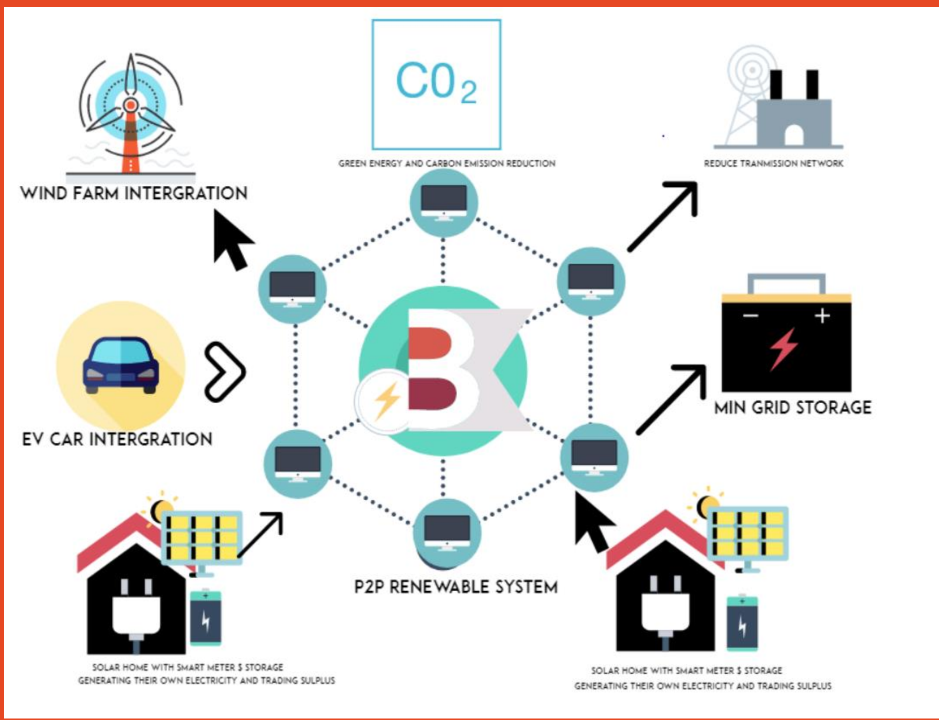



Figure 6. 3 The system involves, participant, assets and transaction of assets:

The diagram show the P2Pproject (P2P project)

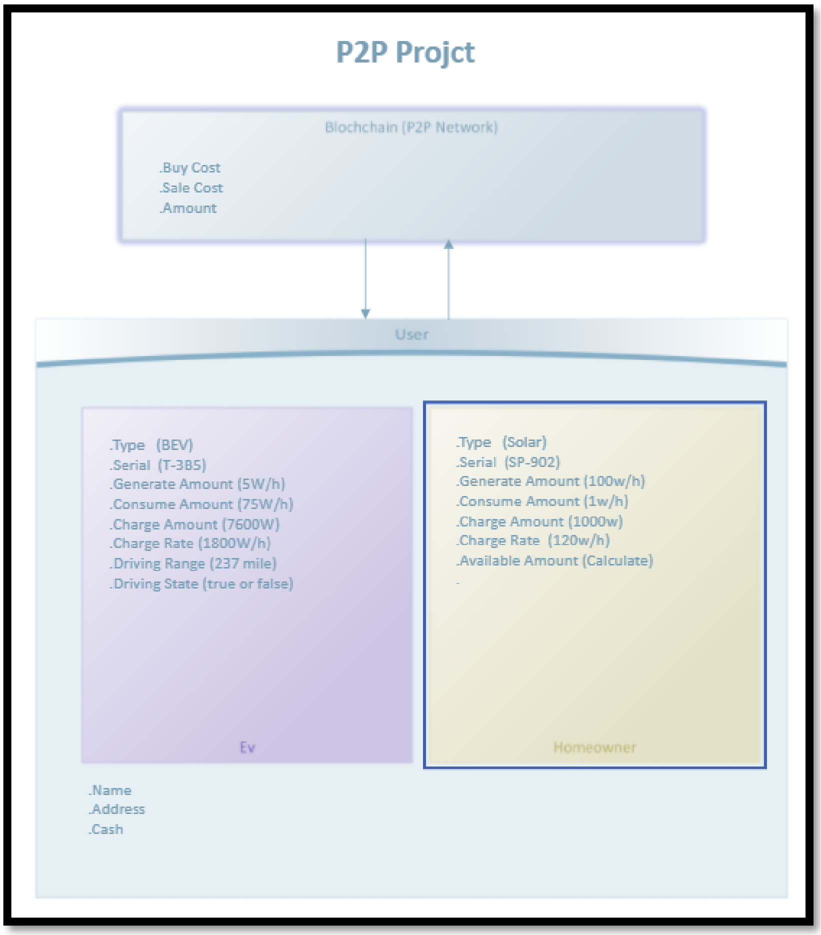



Figure 6. 4 P2P network setup

The diagram below show the P2P Network constant, Varible and Function.

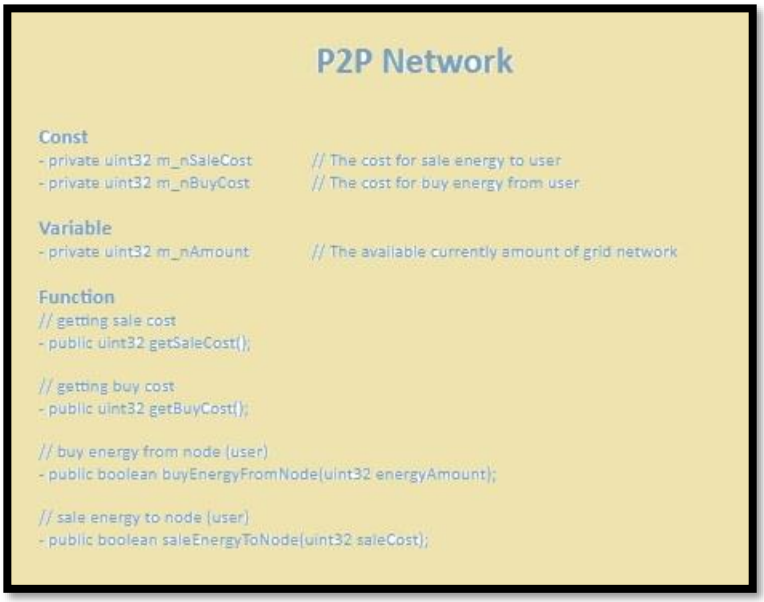



Figure 6. 5 P2P Network

The Users regertration

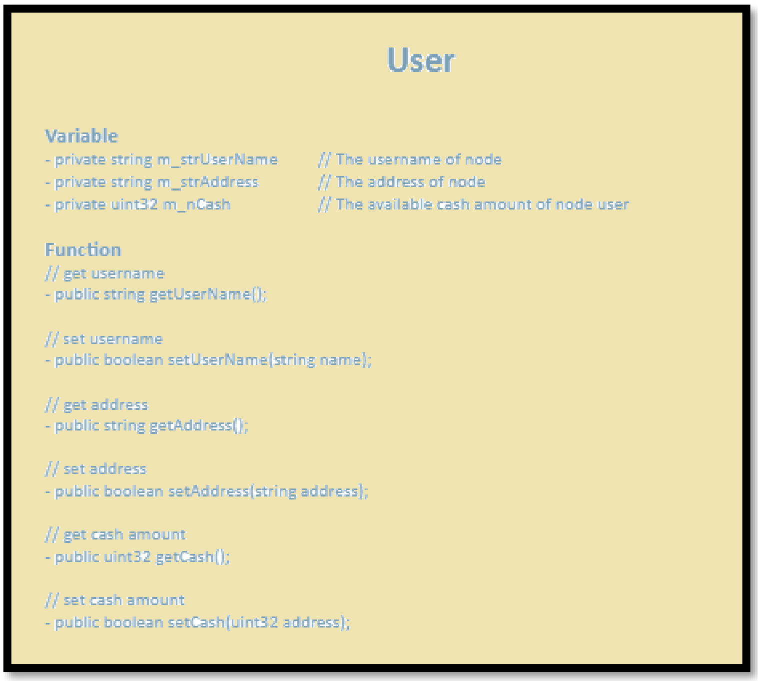
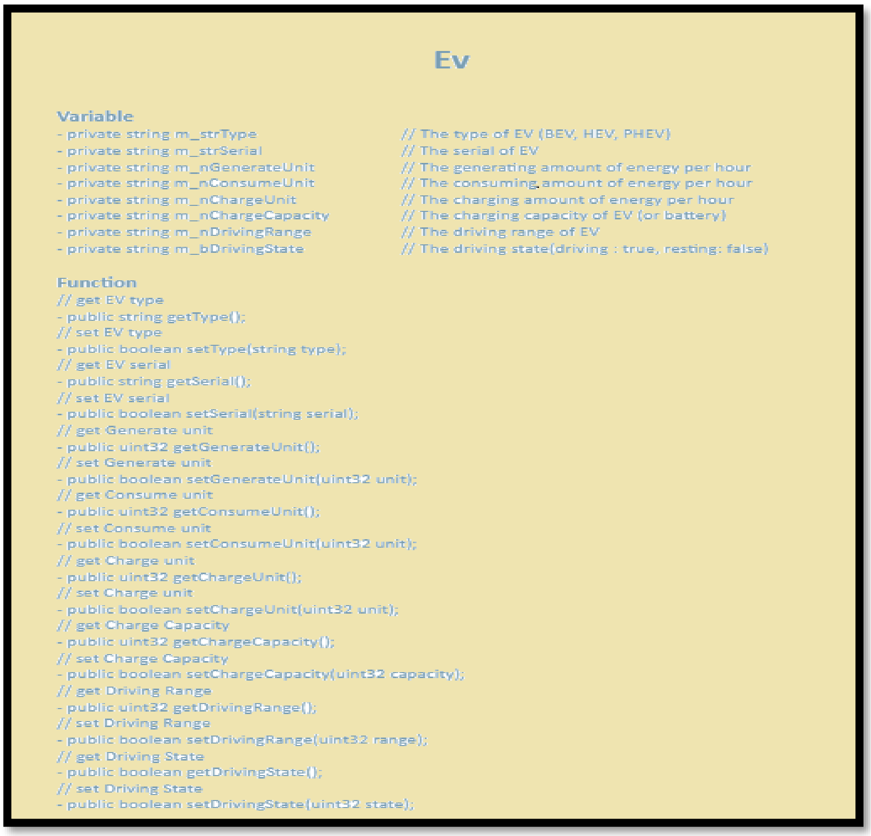



Figure 6. 6 P2P User Registration

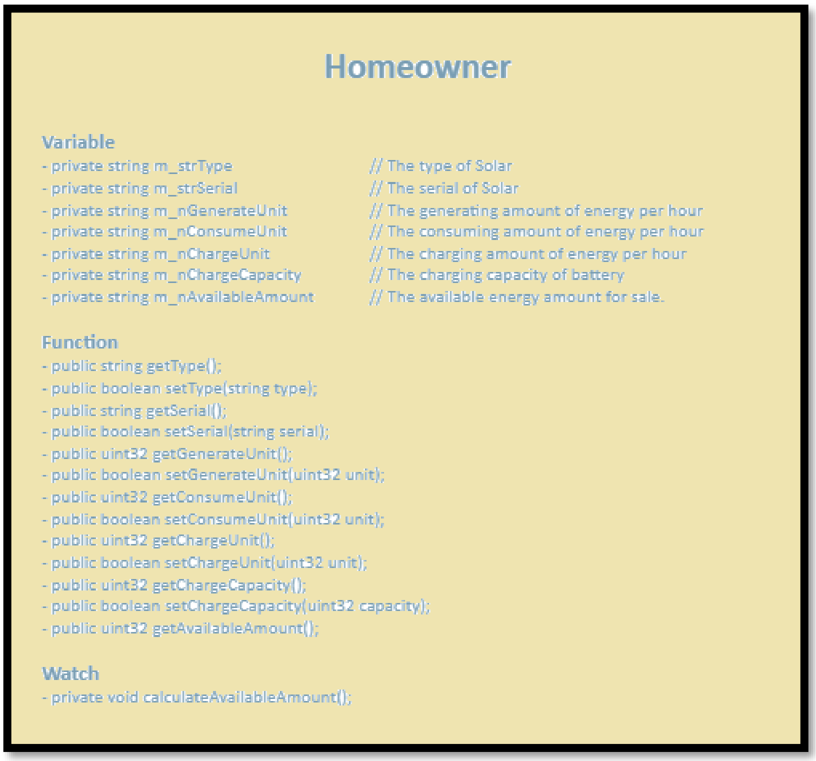


```
Ev

Variable
- private string m_strType              // The type of EV (BEV, HEV, PHEV)
- private string m_strSerial            // The serial of EV
- private string m_nGenerateUnit        // The generating amount of energy per hour
- private string m_nConsumeUnit         // The consuming amount of energy per hour
- private string m_nChargeUnit          // The charging amount of energy per hour
- private string m_nChargeCapacity      // The charging capacity of EV (or battery)
- private string m_nDrivingRange        // The driving range of EV
- private string m_bDrivingState        // The driving state(driving : true, resting: false)

Function
// get EV type
- public string getType();
// set EV type
- public boolean setType(string type);
// get EV serial
- public string getSerial();
// set EV serial
- public boolean setSerial(string serial);
// get Generate unit
- public uint32 getGenerateUnit();
// set Generate unit
- public boolean setGenerateUnit(uint32 unit);
// get Consume unit
- public uint32 getConsumeUnit();
// set Consume unit
- public boolean setConsumeUnit(uint32 unit);
// get Charge unit
- public uint32 getChargeUnit();
// set Charge unit
- public boolean setChargeUnit(uint32 unit);
// get Charge Capacity
- public uint32 getChargeCapacity();
// set Charge Capacity
- public boolean setChargeCapacity(uint32 capacity);
// get Driving Range
- public uint32 getDrivingRange();
// set Driving Range
- public boolean setDrivingRange(uint32 range);
// get Driving State
- public boolean getDrivingState();
// set Driving State
- public boolean setDrivingState(uint32 state);
```

Figure 6. 7 EV properties



```
Homeowner

Variable
- private string m_strType              // The type of Solar
- private string m_strSerial            // The serial of Solar
- private string m_nGenerateUnit        // The generating amount of energy per hour
- private string m_nConsumeUnit         // The consuming amount of energy per hour
- private string m_nChargeUnit          // The charging amount of energy per hour
- private string m_nChargeCapacity      // The charging capacity of battery
- private string m_nAvailableAmount     // The available energy amount for sale.

Function
- public string getType();
- public boolean setType(string type);
- public string getSerial();
- public boolean setSerial(string serial);
- public uint32 getGenerateUnit();
- public boolean setGenerateUnit(uint32 unit);
- public uint32 getConsumeUnit();
- public boolean setConsumeUnit(uint32 unit);
- public uint32 getChargeUnit();
- public boolean setChargeUnit(uint32 unit);
- public uint32 getChargeCapacity();
- public boolean setChargeCapacity(uint32 capacity);
- public uint32 getAvailableAmount();

Watch
- private void calculateAvailableAmount();
```

Figure 6. 8 HomeOwners properties

## 6.3 The Smart Contract for *SolarChain* Energy Network By Using Truffle

Truffle is a popular development framework for Ethereum that provides tools for developing, testing, and deploying smart contracts. Truffle can be installed using npm by running the following command: npm install -g truffle. Truffle for VSCode streamlines the process of creating, building, debugging, and deploying smart contracts on Ethereum and EVM-compatible blockchains.

- To compile npx truffle compile
- To deploy on Rinkeby, yarn truffle deploy --network rinkeby
- To deploy on Mumbai, yarn truffle deploy --network mumbai
- To deploy on Polygon, yarn truffle deploy --network polygon
- To verify npx truffle run verify [ContractName1 ContractName2 ...] --network [NetworkName]

**Write and deploy the smart contract**

The smart contract was written in Solidity, which is the programming language used for Ethereum smart contracts. The smart contract can then be compiled and deployed to the local blockchain using Truffle.

Smart Contract Features:

1. Smart grid dynamic pricing for automatic balancing of total supply and total demand within a microgrid,
2. Interval
3. Bid
4. Consume
5. Autonomous and automatic transactions
6. Buy
7. Prevention of duoble Sell
8. Go
9. Charge
10. View
11. Experiment on a testbed (Node.js and web3.js API to access Ethereum)
12. simulation via personas (virtual consumers and prosumers generated from benchmark). Detailed

## 6.4 Smart Grid intergration

The EnergyMarket's class for the SmartGrid. Prosumers, electric vehicles, and solar-powered homes can register with the EnergyMarket and take part in the auction. Participants can register to become a part of the smart grid infrastructure by taking the SmartGrid class.

```python
class SmartGrid:
    def __init__(self):
        self.participants = []

    def register_participant(self, participant):
        self.participants.append(participant)

class EnergyMarket:
    def __init__(self):
        self.prosumers = []
        self.evs = []
        self.homes_with_solar_pv = []
        self.smart_grid = SmartGrid()

    def register_prosumer(self, name, email, wallet_address):
        prosumer = Prosumer(name, email, wallet_address)
        self.prosumers.append(prosumer)
        self.smart_grid.register_participant(prosumer)
```

Figure 6. 9 SmartGrid class as part of the EnergyMarket

## 6.5 Interact with the smart contract

Once the smart contract is deployed, it can be interacted with using a web3.js client or a user interface. Web3.js is a JavaScript library that allows developers to interact with the Ethereum blockchain from the browser. A user interface can be developed using a front-end framework, such as React or Angular.

### 6.5.1 Ethereum Remix

The Remix IDE is to complie and deploy contract

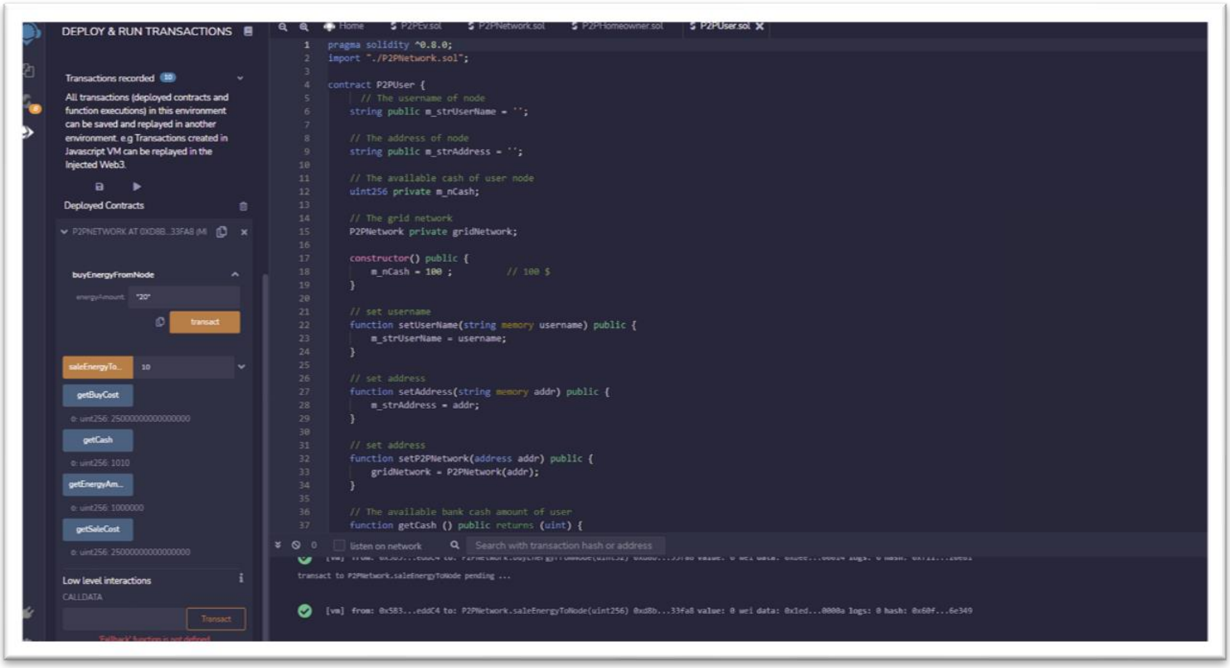



Figure 6. 10 Remix IDE – Deployed smart contract.

### 6.5.2 Define the Auto-Processing of Bids and P2P trading

Autonomous Bidding and P2P Trading:In this part, we define the method for automated bid processing and P2P trade on the Solar Chain Ethereum P2P network. This critical function guarantees that energy transfers between network participants are seamless, efficient, and safe.

**Bidding Process Automation:**

The platform starts by gathering bids from prosumers who want to sell extra energy and consumers who want to buy energy. Smart contracts are used to validate and record these bids on the blockchain in a transparent manner. Bids are evaluated by an automated system based on predetermined parameters such as price, availability, and location. Bids that fit the given parameters are automatically matched, resulting in the P2P trading process being initiated.

**Peer-to-Peer Trading:**

When bids are matched, the platform executes P2P trading on its own. Smart contracts make it possible to move funds securely from consumers to prosumers and vice versa. Energy transactions take place in real time, with the blockchain documenting each stage of the process. As transactions are completed, participants receive notices and confirmations.

The platform ensures that all applicable legislation and standards are followed, ensuring the integrity and legitimacy of P2P trading activity.

Our technology streamlines energy exchange, improves user experience, and develops trust among participants by establishing bid auto-processing and P2P trading. This automation is a key component of our objective to transform sustainable energy practises.

In Algorithm 1: The while loop used by the auto_process() method simulates automatic processing of bids and energy trading. If the bidding time has ended and the market clearing price has been established, it continuously checks to see if this has happened. If not, it waits a predetermined amount of time before starting over. The trade_energy() method's logic can be used to implement the energy trading process once the market clearing price has been determined.

Table 21 Algorithm 1

*Algorithm 1: Algorithm for Define the Auto-Processing of Bids and P2P trading*

```
Class Participant{
        def __init__(self, name, email, wallet_address):
          self.name = name
        self.email = email
        self.wallet_address = wallet_address
          self.bids = []
 def place_bid(self, quantity, price, start_time, end_time):
        bid = {
        'quantity': quantity,
          'price': price,
        'start_time': start_time,
        'end_time': end_time }
        self.bids.append(bid)
def accept_bid(self, bid):
 Logic to  Logic to accept or reject bid
        Pass
def withdraw_funds(self):
          Logic to withdraw funds to Ethereum wallet address
        Pass
class EnergyMarket:
         def __init__(self):
        self.participants = []
        self.bidding_closed = False
        self.market_cleared = False
        def register_participant(self, name, email, wallet_address):
        participant = Participant(name, email, wallet_address)
        self.participants.append(participant)
        def close_bidding(self):
          self.bidding_closed = True
  def create_market_clearing_price(self):
       # Logic to calculate the market clearing price based on supply and demand
```

```
            self.market_cleared = True
            def trade_energy(self):
            # Logic to facilitate energy trading at the market clearing price
            pass
   def auto_process(self, time_interval):
             while not self.bidding_closed:
               print("Processing bids...")
             # Logic to process bids
             time.sleep(time_interval)
 while not self.market_cleared:
             print("Calculating market clearing price...")
             # Logic to calculate market clearing price
             time.sleep(time_interval)
  print("Facilitating energy trading...")
             # Logic to facilitate energy trading
 # Show the outcomes
             For the participant in self.participants, print ("nEnergy Trading Results:"):
             For a bid in participant.bids, print(f"participant.name -
             participant.wallet_address"):
             print(f"Bid: ['quantity'] units at ['price']")

 end
```

Smart contracts also describe how the market is cleared, taking into consideration buy/sell offers for PV and EV generation. For the quantity of EV charging, this technology minimises human interaction. Our proposed system sends value to each other quickly via an Ethereum-based private blockchain application. Prosumers are electricity customers who also produce electricity. Prosumers can sell extra electricity to charging stations using a peer-to-peer (P2Ptrading mechanism. They can charge their own electric vehicles while also profiting from the sale of surplus electricity. Solar panels are used by many prosumers to generate electricity. Our proposed system is built on the blockchain, which ensures that prosumers, charging station operators, and electric car owners may interact safely and securely. It creates a smart contract-based environment in which users can put their trust in the system. The technology will deduct the agreed-upon billing rate from wallets automatically.

Transactions and blocks are generated by blockchain, and each block must be authenticated by peer nodes using a predetermined consensus mechanism. The diagram depicts a graphic representation of the renewable house and electric vehicle data integration scenario. Solar type, solar series, generate unit, consume unit, charge unit, capacity, and surplus capacity are all shown in the register of homeowners (solar) properties.

### 6.5.3 Automatic Bidding Matching Algorithm

The system proposed using automatic bidding matching algorithm.

Users can set their maximum bid for an item or service and have it automatically matched with other bids. When a user enters a maximum bid, the system will automatically increase it to maintain the user's position as the highest bidder until the user's maximum is reached. This function saves time and effort by removing the need for bidders to manually check on and submit fresh bids at regular intervals.

In the pseudocode below, the algorithm checks each bid in the bidding list and keeps track of the highest bid and highest bidder. If the maximum bid is less than the highest bid, the system calculates a new bid amount for the max bidder based on the minimum increment and places a new bid on their behalf.

The calculate_new_bid_amount function is called to calculate the new bid amount based on the minimum increment and the current highest and max bids. The function checks if the new bid amount exceeds the max bid and adjusts the new bid amount accordingly.

The place_bid function is called to place the new bid. The function checks whether the bidder has sufficient funds to cover the bid and adds the bid to the list of bids if they do. If the bidder does not have sufficient funds, the function notifies them that they cannot place the bid.

This is a simplified example, and the exact implementation will depend on the specific requirements of your bidding system.

Table 22 Algorithm 2

*Algorithm 2: Algorithm for Automatic Bid Matching*

```
Input: Initialize Variable.
Highest_Bid =0
highest_bidder = null
max_bid = 0
max_bidder = null
Loop through all Bids
for each bid in bids: Check if the bid is higher than the current highest bid
    if bid.amount > highest_bid:
    highest_bid = bid.amount
    highest_bidder = bid.bidder
    Check if the bid is higher than the current max bid
    if bid.amount > max_bid:
    max_bid = bid.amount
    max_bidder = bid.bidder
    If the max bid is less than the highest bid, place a new bid for the max bidder
    if max_bid < highest_bid:
    new_bid_amount = calculate_new_bid_amount(max_bid, highest_bid,
    minimum_increment)
    new_bidder = max_bidder
    place_bid(new_bidder, new_bid_amount)
    Function to calculate the new bid amount
        function calculate_new_bid_amount(max_bid, highest_bid,
        minimum_increment):
        Calculate the new bid amount based on the minimum increment
        new_bid_amount = highest_bid + minimum_increment
    Check if the new bid amount exceeds the max bid
        if new_bid_amount > max_bid:
```

```
            new_bid_amount = max_bid + minimum_increment
            new_bid_amount = highest_bid + minimum_increment
            return new_bid_amount
        Function to place a bid
            function place_bid(bidder, amount):
        Verify bidder has sufficient funds to cover the bid
            if bidder.balance >= amount:
        Deduct the bid amount from the bidder's account
            bidder.balance -= amount
        Add the bid to the list of bids
            bids.add (new Bid(bidder, amount))
        Else:
        Notify the bidder that they do not have sufficient funds to place the bid
    notify_bidder_insufficient_funds(bidder)
    end
```

### 6.5.4 The comparison between the Time-of-Use Bidding and Smart Contract Automation strategies

Comparing the Bidding strategies

The research evaluation of smart contract automation vs time-of-use bidding.

A peer-to-peer blockchain-based Ethereum energy trading platform can be used to conduct bids for solar PV, smart grid, and electric vehicles (EVs).

Parameters:

- time_period: This variable represents the number of hours in the simulation.
- peak_hours: It is a list that specifies the hours during which the demand is considered as peak hours.
- peak_price and off_peak_price: These variables define the price per unit of energy during peak and off-peak hours, respectively.

- energy_demand: This list represents the energy demand in kilowatt-hours (kWh) for each hour of the time period.

**Time-of-Use Bidding:**

The time_of_use_bidding() function calculates the bid prices, total cost, and total revenue for the Time-of-Use Bidding strategy.

It iterates over each hour of the time period and determines the bid price based on whether it is a peak or off-peak hour.

The function keeps track of the bid prices in the prices list and calculates the total cost by multiplying the bid price with the corresponding energy demand for each hour.

In this example, the total revenue is assumed to be the same as the total cost for simplicity.

## 6.6 Testing P2P Network Project implementation End to End

## 6.7 Set up the Ethereum Development Environment

In this study, the Ethereum blockchain was selected for this experiment. There are different pieces of DApp technology but this work follow steps below:

Install a text editor: A text editor is required to write and edit code. There are several text editors available, such as Visual Studio Code, Sublime Text, and Atom.

Install Node.js and npm: Node.js is a JavaScript runtime that allows developers to run JavaScript outside of the browser. npm is the package manager for Node.js. Both Node.js and npm can be installed from the official Node.js website. Also, Python software is used to experimental setup and algorithm is written in python code.

To config Ethereum neworks and deploy contracts, Rinkeby Test Network was set up to run instance on MetaMask applications. MetaMask is a pioneering tool that enables user interactions and experiences on Web3. It is currently available on Android and iOS devices as a browser extension and as a mobile app. The goal of this documentation is to show how to create a dapp with MetaMask [178]. To build the framework, the tools needed to write a smart contract and interface with Ethereum blockchain.

- Window 11 computer was used, PowerShell tool was installed by default.
- Visual studio code- When it comes to writing smart contracts, my preferred code editor is Visual Studio Code It's extremely lightweight, packed with community-created extensions, and comes with powerful debugging tools.
- Geth is the Go-based command line interface for running a full Ethereum node. It enables you to do almost anything you would need to do on the blockchain.
- Ganache is a blockchain emulator that allows you to control how the blockchain operates by running tests, executing commands, and inspecting state.

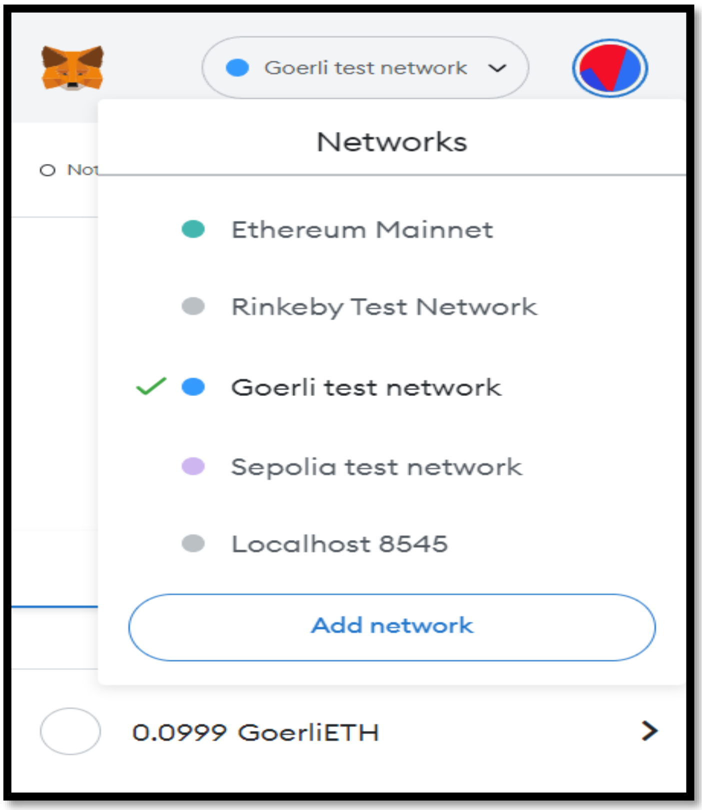



Figure 6. 11 MetaMask Network

Smart contracts built using Solidity in Remix IDE and python script are used to demonstrate the application's proof of concept.. There are four domains for smart contracts. Authorization of electric vehicle users, EV scheduling, charging control, and billing

### 6.7.1 User Registration

The initial step of the model involves the registration of User on the platform. Each users will have a blockchain wallet and an unique address to enable them to set transactions.

```
# Participants Registration
participants = {
    "homes": [
        {
            "type": "solar_pv",
            "properties": {
                "solar_type": "PERC",
                "solar_serial": "SPP72-96H",
                "generate_unit": "10W/H",
                "consume_unit": "150W/H",
                "charging_unit": "600W/H",
                "capacity": "600W",
                "excess_capacity": "120W"
            }
        }
    ],
    "electric_vehicles": [
        {
            "type": "EV",
            "properties": {
                "ev_serial": "EV-500a",
                "generate_unit": "10W/H",
                "consume_unit": "150W/H",
                "charging_unit": "2000W/H",
                "capacity": "2500W",
                "driving_range": "200KM"
            }
        }
    ],
    "smart_grid": {
        "type": "vehicle-to-grid"
    }
}
```

Figure 6. 12 Participant of simulation

Table 23 System descriptions of Participants registration, Assets, and Transactions.

| Participants Registration on Private Blockchain/ Ethereum | Assets | Transactions |
|---|---|---|
| ❖ **Homes/ Buildings with Solar PV**<br>❖ **Homes/ Buildings with Solar PV**<br>❖ **Electric Vehicles(EV)**<br>❖ **Smart Grid (Vehicle-to-Grid)** | Homeowners (Solar) Properties:<br>❖ Solar Type : PERC<br>❖ Solar Serial : SPP72-96H<br>❖ Generate Unit :10W/H<br>❖ Consume Unit: 150W/H<br>❖ Charging Unit :600W/H<br>❖ Capacity : 600W<br>❖ Excess Capacity: 120W<br><br>EV Properties:<br>❖ EV type: BEV<br>❖ EV Serial : EV-500a<br>❖ Generate Unit :10W/H<br>❖ Consume Unit: 150W/H<br>❖ Charging Unit :2000W/H<br>❖ Capacity : 2500W<br>❖ Driving Range :200KM | Bidding Module:<br>❖ Buy<br>❖ Sell<br><br>AcceptBidOffer:<br>❖ PV Offer<br>❖ EV Offer<br><br>Withdrawal Module:<br>❖ Buyer pays from ETH Wallet<br>❖ Seller Receive ETH in wallet<br><br>CloseBidding :<br>❖ Send MCP<br>❖ Interval |

### 6.8 Solar Chain Application P2P Simulation

#### 6.8.1 Simulation of P2P users Interface

This section will discuss the virtual representation or emulation of a P2P user interface (UI) that allows users to engage with a P2P network is referred to as a simulation of a P2P user interface (UI). Individual computers or devices, known as peers, connect and share resources directly with one another in a P2P network, rather than depending on a centralised server. A P2P UI simulation often contains components that promote peer finding, resource sharing, and peer communication. The functions and interactions of participants inside a private blockchain or Ethereum network are demonstrated by these examples. Owners of solar PV systems produce renewable energy, EV owners drive cleaner vehicles, and V2G members support demand response and grid stability initiatives.

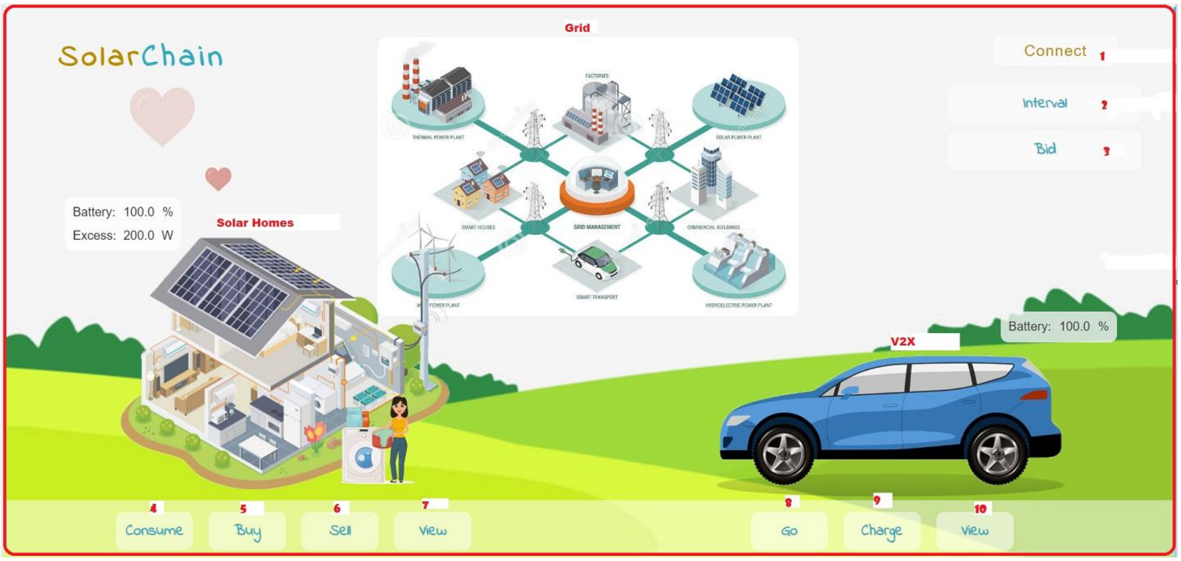



Figure 6. 13 Proposed Solar chain project platform.

Each group of participants owns and maintains the name Peer. A peer is a network entity that commits transactions and manages/maintains a ledger on which a smart contract executes to encode assets and transaction instructions (i.e., business logic agreed by participants in the network). Individuals can buy and sell their energy on a peer-to-peer network (Improvement of EV battery technology and energy storage). Ordering Service (OS) is a node that provides participants with shared communication channels, offers a broadcast service for messages containing transactions, and implements service delivery guarantees. The Certificate Authority (CA) registers identities and issues enrollment certificates to participants. Also, users can pay per usage and sell excess energy generated. The blockchain technology will facilitate transactions and track energy storage. Token exchange between suppliers and prosumers and incentives for renewable energy adoption.

Users interface (UI) have been developed and Users can run the simulation by using 10 buttons by default. Ethereum application has been tested for the required application and has showed its limits for the use case. Ethereum application was use due to the upgrade of distribution consensus model is Proof of work (PoW). The smart contract allows the system to handle a bidding mechanism between agents and prosumers.

Features and Components:

- Connect: Users click this button to connect to the primary network. You can use MetaMask or other Ethereum wallets and use the Rinkeby Test network.
- Interval: The system uses intervals to track the energy consumption and charge the user accordingly. This ensures that the user is charged accurately and prevents overcharging.
- Bid: The system uses a bidding system to allow users to bid on available energy. This ensures that the energy is allocated efficiently and reduces the overall cost of energy. The system uses autonomous and automatic transactions to ensure that the energy transactions are secure, transparent, and efficient.
- Consume: The system allows users to consume energy from the microgrid. This ensures that the energy is utilized efficiently and reduces the overall cost of energy. It shows how homeowners consume energy. In the project, the washing machine is running.

Figure 6. 14 Washing machine

At the same time, the amount of battery held in the homeowner's attribute table is also reduced.

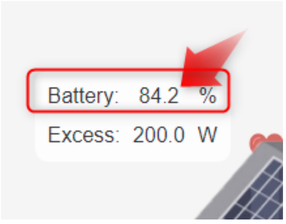



Figure 6. 15 Battery charging capacity

When the energy reserve drops to 20%, all consumption processes are stopped, and consumption cannot continue until energy is recharged.

- Participants: Participants are those involved in the buying and selling of excess solar PV, EV generation in a community, i.e., property owners, of which there are two types: prosumer – a homeowner with rooftop solar PV, EV whose house can both consume and produce electricity – and consumer – a homeowner without PV whose house can only consume electricity. Each User is registered with the following parameters: 'balance,' 'email,' 'first Name,' and 'last Name.' The 'balance' specifies the homeowner's available digital currency (tokens), which is used to buy and sell solar energy in this blockchain network. A unique ID, which is an email address, is used to identify the homeowner. When a transaction (buy/sell electricity) takes place,
- Buyers: This ensures that the user has access to energy when needed and reduces the overall cost of energy. Recharge the homeowner's energy. In this case, the homeowner must be a node in the main network (P2PNetwork). By paying a specified amount, you can refill the corresponding amount of energy.


Figure 6. 16 Buyer button

- Sell:Solar panels owned by homeowner is generating electricity. When the battery you own is sufficiently charged, you can sell the excess electricity by connecting it to the P2P network.


Figure 6. 17 Seller Button

At this time, the homeowner will be paid according to the amount of energy sold at the price specified by the P2P network.

- Prevention of double sell: The system prevents double sell of energy by using smart contracts to ensure that the energy is allocated only to the user who has bought it.
- View: The system allows users to view their energy consumption and charges. This ensures that the user has transparency and control over their energy usage.

You can request and view the property values of homeowners registered in the P2P network.

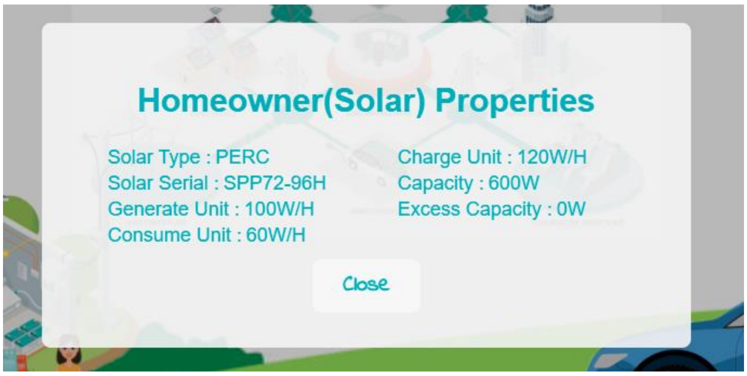



Figure 6. 18 Homeowners Properties

- Transactions: Different types of transactions are defined in this work to facilitate the exchange of excess PV and EV generation, such as 'Accept Offer Broadcast,' 'PV Offer,' 'BUY Offer,' and 'Close Bidding.' Each transaction necessitates the 'listing id' parameter, which specifies the date and time of the solar electricity exchange. Accept Offer Broadcast' –This is the broadcast message that the system automatically sends to all participants at the start of each hour. The broadcast message informs all homeowners that the system is now open for offers to buy/sell excess PV/EV generation, signalling the beginning of the bidding period.

'PV Offer' –After receiving the broadcast message, prosumers (identified by unique IDs or email addresses of homeowners) can send offers to sell their excess PV generation ('kWh available', kWh) with an optional reserve price ('reserve Price', token/kWh).

BUY Offer' –After receiving the broadcast message, consumers (identified by homeowners' unique IDs or email addresses) can send bids to buy energy from PV, specifying the amount of energy required ('kWh Quantity', kWh) and the price they are willing to pay ('Bid Price', token/kWh).

Close Bidding' –This transaction specifies that the bidding period has ended, and the designed smart contract has been launched to process the PV trading among homeowners.

Go: The system allows users to start and stop charging their EVs. This ensures that the energy is utilized efficiently and reduces the overall cost of energy.It simulates the energy consumption process of EVs registered in the P2P network. The consumption process is shown as the driving process of the EV. When the EV's energy possession drops to 50%, operation is automatically stopped.


Figure 6. 19 EV Registration

Charge: Users can charge the EV's energy with an EV charging station or a regular charger. This process is shown as an optional option in the project, and if you choose, you can pay the corresponding amount and recharge your energy.

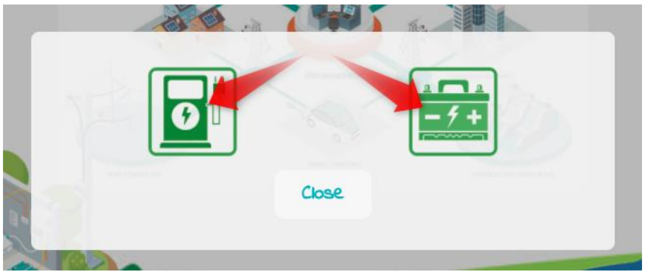



Figure 6. 20 EV charging station


Figure 6. 21 EV Properties

1. Smart Grids for dynamic pricing for automatic balancing of total supply and total demand within a microgrid.

2. Setting interval period/ Close interval, Token price and total supply, 3. automated and autonomous operation.

4. Market clearing price (MCP),

5. Experiment on a testbed (Node.js and web3.js API to access Ethereum Virtual Machine), and 6. Frontend user simulation (virtual consumers and prosumers generated from benchmark). The diagram below show the process flow:

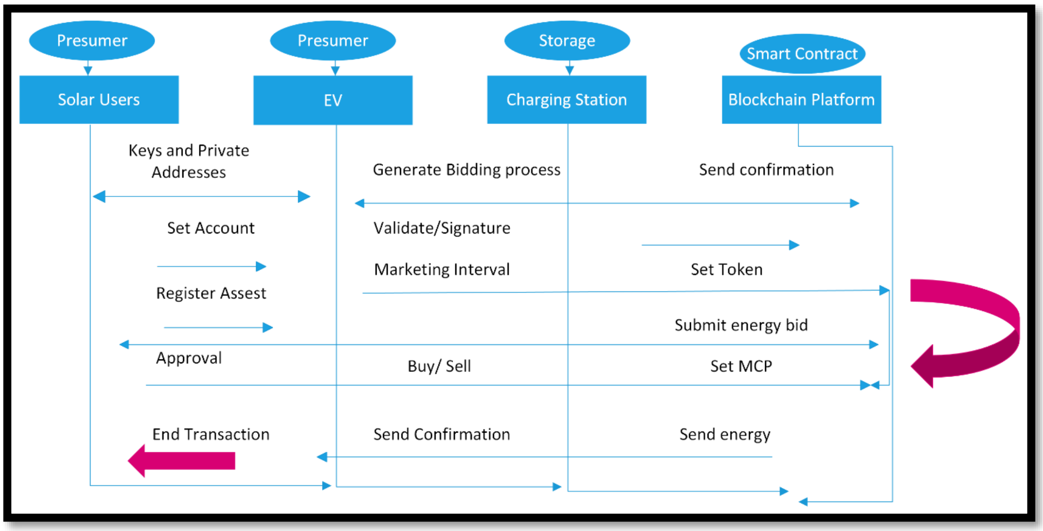



Figure 6. 22 Process flow diagram for p2p proposed system.

## 6.9 *SolarChain* Network – User case

### 6.9.1 Initialization/ User Registration

Prosumers (EV or Homeowners) Registration: The first step in joining a blockchain network as a prosumer is to register as a participant. Typically, this process entails opening an account and providing details regarding the energy generation or storage assets that the prosumer owns. The kind and capacity of renewable energy systems as well as the size and capacity of an EV battery, may be included in this information. Once registered, prosumers can participate in the energy market by transacting energy directly with other network users. Smart contracts, which are self-executing agreements with the terms of the agreement put directly into code, can be used to do this. Smart contracts can automate the trading process and guarantee that all parties to a transaction adhere to the terms which have been agreed upon.

Homeowners register there PV assets in the deployed blockchain network. The diagram depicts a graphic representation of the renewable house and electric vehicle data integration scenario. Solar type, solar series, generate unit, consume unit, charge unit, capacity, and surplus capacity are all shown in the register of homeowners (solar) properties.

Registration Details of EV properties:


Figure 6. 23 EV type, EV serial, create unit, consume unit, charging unit, capacity, and driving range are all listed in the EV properties registration.

Registration Details of Home Owners:

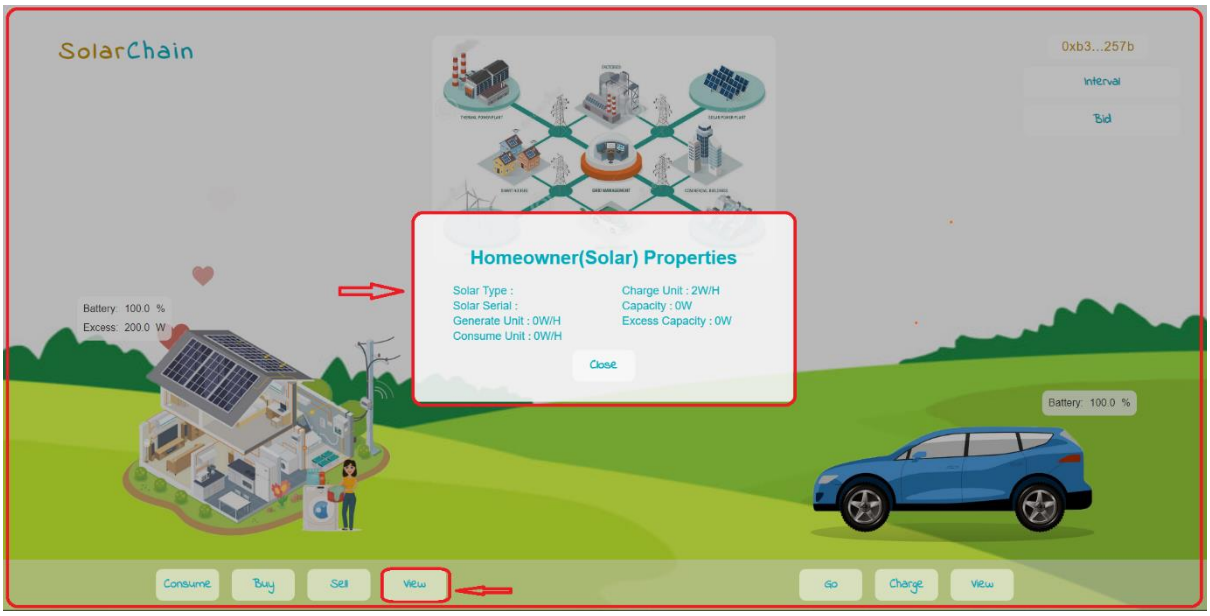



Figure 6. 24 Solar type, Solar serial, generation unit, consume unit, charging unit, capacity, and Excess capacity

### 6.9.2 Interval

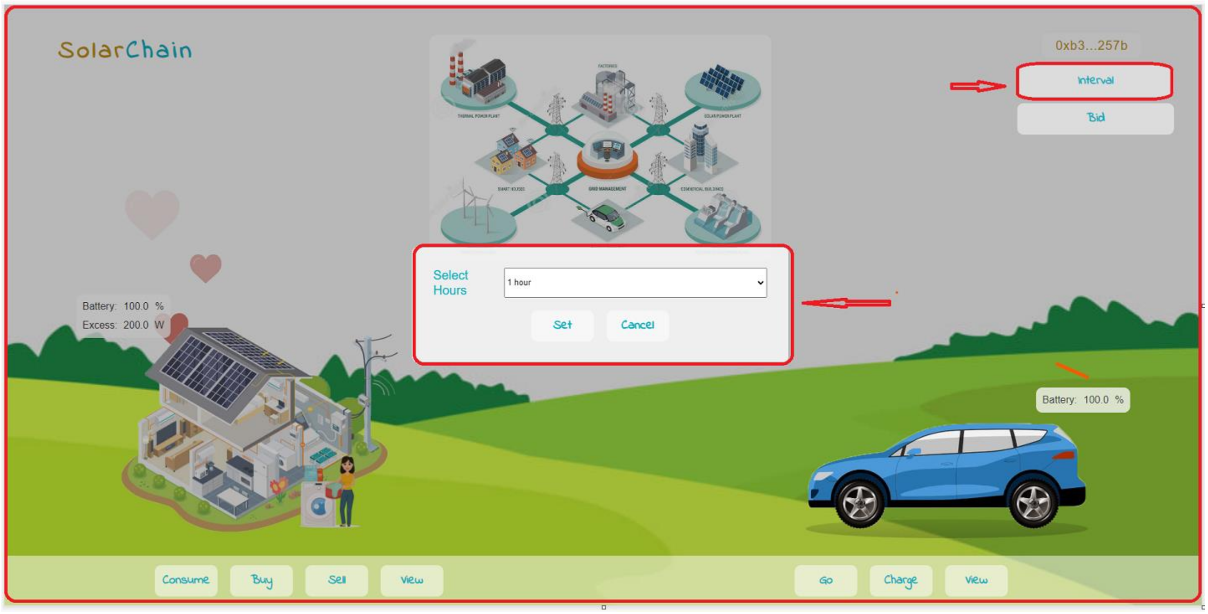



Figure 6. 25 Set market Interval

### 6.9.3 Auto Process Bidding Module

The bidding module component of the home owners, EV User that allows users to bid on available energy within the microgrid. The bidding module ensures that the energy is allocated efficiently and reduces the overall cost of energy by allowing users to compete with each other to purchase energy at the lowest possible price.

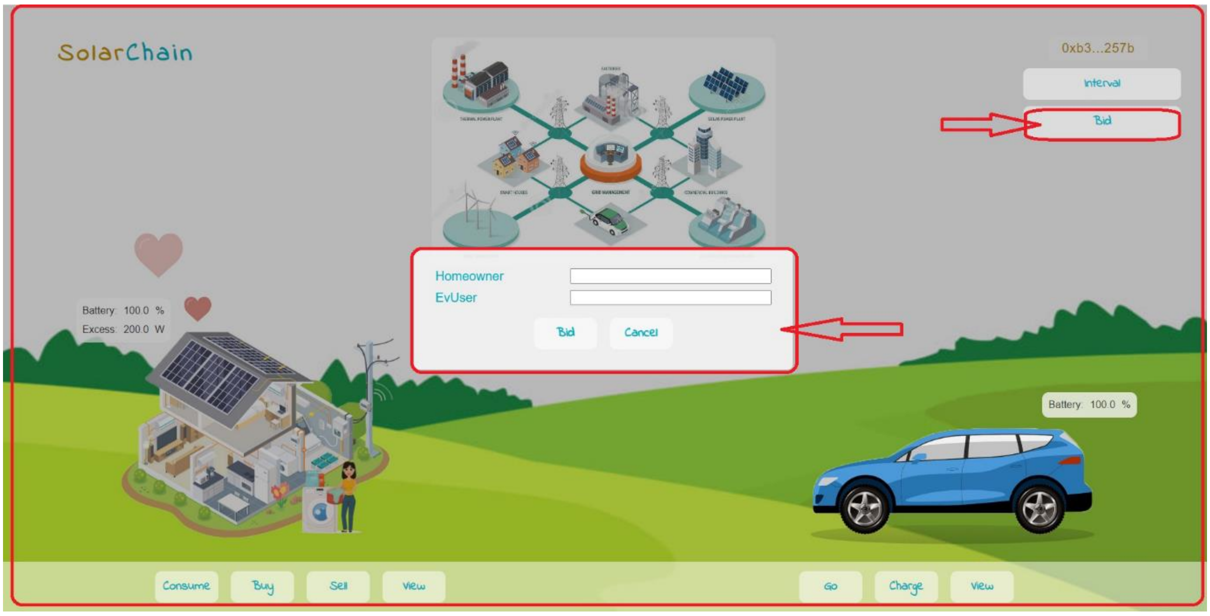



Figure 6. 26 Setting initial Bid for Homeowners and EV Users

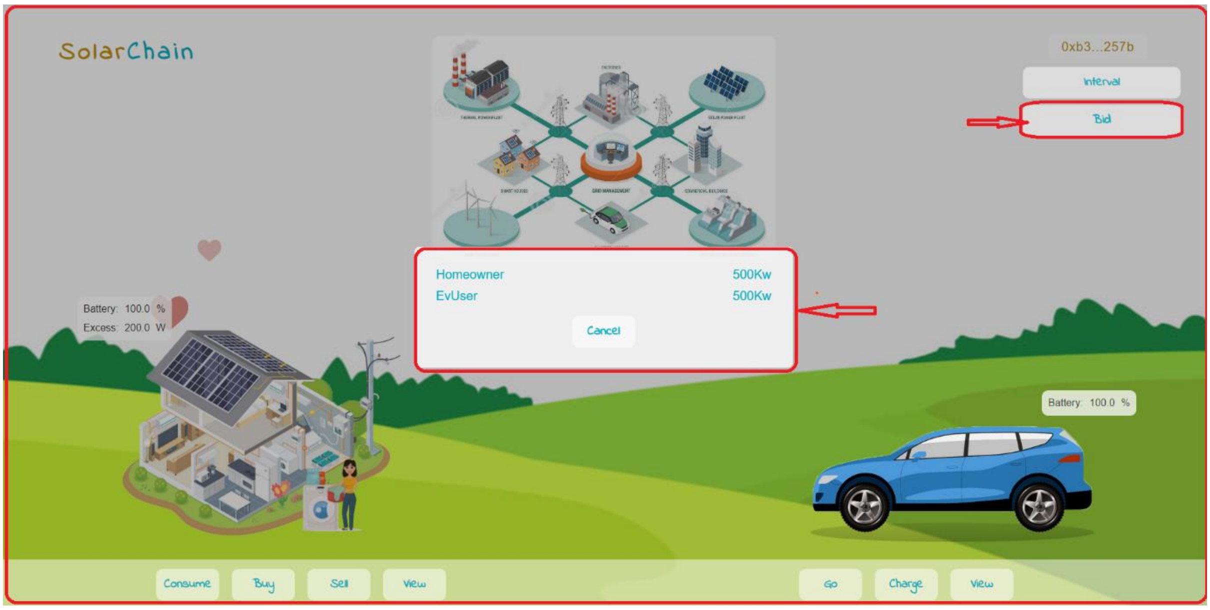



Figure 6. 27 Enter Bid values Kilo Watts (KW)

The bidding module works by allowing users to submit bids for a certain amount of energy at a certain price. The system then evaluates the bids and allocates the energy to the user with the highest bid at the lowest price. This ensures that the energy is allocated efficiently and fairly and reduces the overall cost of energy by ensuring that users pay only what they are willing to pay for the energy. Ether is the name of the cryptocurrency for the Ethereum blockchain application. Ether is the substance that make Ethereum transaction possible[179].

Bidding rules for the implementation:

- Minimum Bid Increment: The system may set a minimum bid increment, which is the minimum amount by which a bidder can increase their bid. This ensures that bids are competitive and that the bidding process is efficient.
- Time Limit on Bids: The system may set a time limit on bids to ensure that the bidding process is efficient and that bids are submitted in a timely manner. For example, the system may allow bidders to submit bids for a certain amount of time and then automatically allocate the energy to the highest bidder at the end of the bidding period.
- Bid Validation: The system may validate bids to ensure that they are valid and meet certain criteria. For example, the system may require bidders to provide a valid payment method or to have sufficient funds in their account before submitting a bid.
- Maximum Bid Amount: The system may set a maximum bid amount to prevent bidders from overbidding and driving up the cost of energy. This ensures that the energy is allocated efficiently and at a fair price.
- Bid Transparency: The system may make the bidding process transparent by allowing bidders to see the bids of other users. This promotes fair competition and ensures that the bidding process is transparent and efficient.

bidding rules are an important component of the EV Charging System that ensures that the bidding process is fair, transparent, and efficient, and that energy is allocated in the most optimal way possible.

The bidding module is an important component of the P2P trading platform that ensures efficient and cost-effective energy allocation within the microgrid. Also, bidding rules are an important component in the P2P system that ensures that the bidding process is fair, transparent, and efficient, and that energy is allocated in the most optimal way possible[180].

### 6.9.4 Use Case: Homer homeowner with excess solar

Explore a real-world use case involving Homer proprietor, a prosumer with a solar panel installation, to demonstrate the applicability and benefits of the Solar Chain Ethereum P2P platform. The homeowner possesses a residential solar panel system that produces excess electricity on sunny days. The homeowner's connection to the Solar Chain platform enables him to trade excess energy with neighbouring consumers. She has an electric vehicle (EV) that she charges at her residence.

**Use Case Illustration:**

Generation of Solar Energy: On a Sunny day, Homeowner's solar panels generate more than 10 kWh of electricity. Typically, this excess energy would be wasted, but with Solar Chain, Alice can utilise it for economic and environmental gains.

The homeowner enters into her Solar Chain account and creates an offer to sell her excess energy. He specifies the quantity (10 kWh), pricing (market-competitive rates), and duration (24 hours) for her proposal. The offer is posted to the Solar Chain market.

Bid Matching: To match bids, the Solar Chain platform employs a sophisticated algorithm. In this instance, the homeowner's proposal is matched with a nearby electricity-needing presumer.

Peer-to-Peer Energy Transfer: Following the effective matching of bids, a smart contract facilitates P2P energy transfers. Prosumers' residence receives 10 kWh of excess solar energy, reducing his reliance on the grid.

Meanwhile, Homeowners' EV is hooked in and programmed to charge when surplus solar energy is available. Integrated with Solar Chain, the intelligent charging system automatically adjusts the charging rate to maximise the use of free solar energy. Real-Time Monitoring: Both Homeowner and Prosumer can monitor the energy transfer and consumption in real time through the Solar Chain platform. Using blockchain technology, transparency and trust are assured. At the conclusion of the 24-hour duration, the smart contract initiates settlement and savings. The homeowner's account is debited for the amount of energy consumed, and the homeowner is compensated for any excess energy. Both parties enjoy lesser energy costs compared to standard utility rates.

**The benefits are:**

- The homeowner reduces his electricity expenditure and profits from the sale of excess energy.
- The consumer enjoys pure energy and cost savings.
- Decreased grid stress during peak hours.

- Utilisation of energy that does not harm the environment.
- Smart contracts and blockchain enable automation and transparency.

This use case exemplifies how the Solar Chain Ethereum P2P platform transforms energy generation, distribution, and consumption, making it more sustainable, cost-effective, and user-centric. It enables individuals such as Homerowner to actively participate in the energy market while promoting the adoption of renewable energy.

### 6.9.5 Market Clearing Pricing

Market clearing price is the price at which the supply and demand for a particular product or service are balanced, resulting in the optimal allocation of resources. In a market economy, the market clearing price is determined by the interaction between buyers and sellers through the forces of supply and demand.

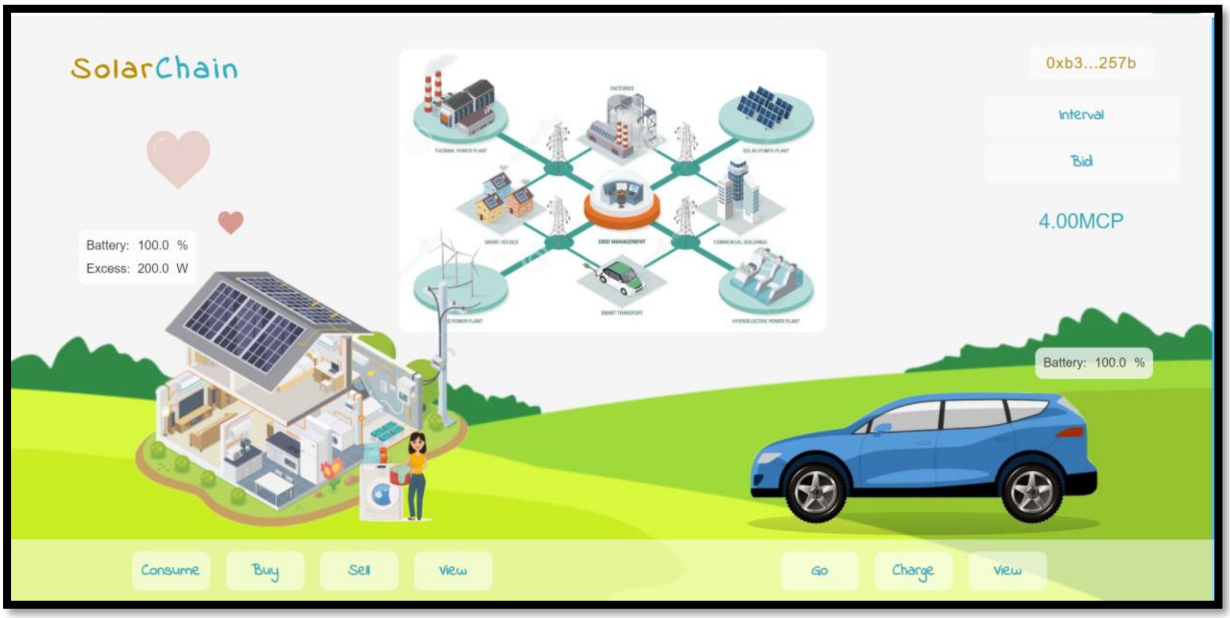



Figure 6. 28 Market clearing price (MCP) value

The market clearing price is the equilibrium price where the quantity supplied of a product or service is equal to the quantity demanded by consumers. This price can change as market conditions change, such as shifts in consumer preferences, changes in the cost of production, or changes in government regulations. Understanding the market clearing price is important for businesses and policymakers to make informed decisions about production, pricing, and resource allocation.

Overall, the MCP formula is a key tool for determining the market price of electricity in a competitive market, and plays a critical role in ensuring the efficient operation and optimization of the electricity system.

let's consider an example of the market clearing price formula for a hypothetical Vehicle to Grid (V2G) energy trading system.

Assume that the demand curve for electricity is represented by the equation:

$$Qd = 500 - 10P$$

Where Qd is the quantity of electricity demanded and P is the price of electricity. Assume that the supply curve for electricity from V2G is represented by the equation:

$$Qs = 100 + 15P$$

Where Qs is the quantity of electricity supplied from V2G.To find the market clearing price for V2G electricity, we can set the quantity demanded equal to the quantity supplied:

$$500 - 10P = 100 + 15P$$

Solving for P, we get: $25P = 400$

$$P = 16$$

Therefore, the market clearing price for V2G electricity is £16. At this price, the quantity demanded is 340 units (500 - 10P = 340) and the quantity supplied from V2G is also 340 units (100 + 15P = 340).

This means that the market is in balance, and all buyers who wish to purchase electricity from V2G at this price can do so, while all sellers who wish to sell electricity from V2G at this price can do so as well. Any deviation from this price would result in excess supply or demand, and the market would adjust to return to the market clearing price.It's worth noting that in a real V2G energy trading system, there would be more factors to consider, such as the availability of electric vehicles, the level of demand for electricity at different times of day, and the cost of charging and discharging electric vehicles. However, the market clearing price formula provides a useful starting point for understanding how prices are determined in a V2G energy trading system.

### 6.9.6 Use case: Optimising Energy Consumption with Solar Chain P2P Network

Homeowner is a residential prosumer with an installed solar panel system on her roof. During sunny days, he generates an excess of electricity, whereas he occasionally encounters energy shortages at night or on cloudy days. To maximise his solar energy and guarantee a reliable energy supply.

The scenario:

Energy Surplus and Deficit: During sunny afternoons, the solar panels produce excess electricity, which is stored in her batteries. Evenings and cloudy days necessitate his reliance on utility electricity. The homeowner connects his solar panel system and household battery to the Solar Chain peer-to-peer network. He sets his preferences, including the minimum price he is willing to accept for selling excess energy and the maximum price she is willing to pay for purchasing additional energy. Real-time Monitoring: Homeowner can monitor her energy production, consumption, and battery status in real-time using the Solar Chain app. He is able to see when his batteries are being charged and when they are being discharged. Bidding and Trading: The Solar Chain platform identifies potential trading partners in the neighbourhood of the Homeowner. It matches his excess energy supply with adjacent consumers who are experiencing energy shortages. Market Clearing Price (MCP): Each trading interval's MCP is computed by the Solar Chain platform. It ensures that surplus energy generated by homeowners is sold at a fair market price. If the MCP meets the homeowner's desired price, the trade is automatically executed.

On a sunny day, when solar generation is high and there are many surplus vendors, homeowners may receive a higher price for their energy. On cloudy days, when demand is greater, he may pay slightly more for grid electricity. Dynamic pricing motivates her to modify her energy consumption to maximise savings. By participating in Solar Chain, a householder optimises her energy consumption and achieves energy independence. He purchases utility electricity during off-peak hours and uses his excess solar energy during peak hours. This reduces her overall energy costs and grid reliance.

Community Benefits: the participation of the householder also benefits his neighbours. They have access to reliable and environmentally-friendly energy sources when they need them, and the householder earns some money by selling his excess energy. Sustainability: Homeowner's use of Solar Chain contributes to a more sustainable energy ecosystem. By maximising her use of photovoltaic energy and decreasing her reliance on fossil fuels, he reduces her carbon footprint.

**The outcome is:**

The householder experiences significant energy bill savings. The community's energy supply is more stable and sustainable. Solar Chain's dynamic pricing incentivizes users, such as homeowners, to align energy consumption with renewable generation, thereby fostering a greener future. This use case illustrates how Solar Chain's P2P network enables prosumers such as homeowners to optimise energy consumption, reduce costs, and contribute to a greener and more resilient energy grid.

### 6.9.7 Buy and Sell

Buying : You can buy Ether from a cryptocurrency exchange by creating an account, verifying your identity, and linking a payment method such as a bank account or credit/debit card. Once you have funded your account, you can buy Ethereum at the current market price.

Sending : To send Ether, you need to have an Ethereum wallet that can hold and send Ethereum. You can use a hardware wallet, a software wallet, or a web wallet to store your Ethereum. Once you have your Ethereum in your wallet, you can send it to another Ethereum address by entering the recipient's address and the amount you want to send.

Receiving : To receive income, you need to provide the sender with your Ethereum address. You can find your Ethereum address in your wallet, and it is a long string of numbers and letters unique to your account. Once the sender sends Ethereum to your address, it will appear in your wallet.

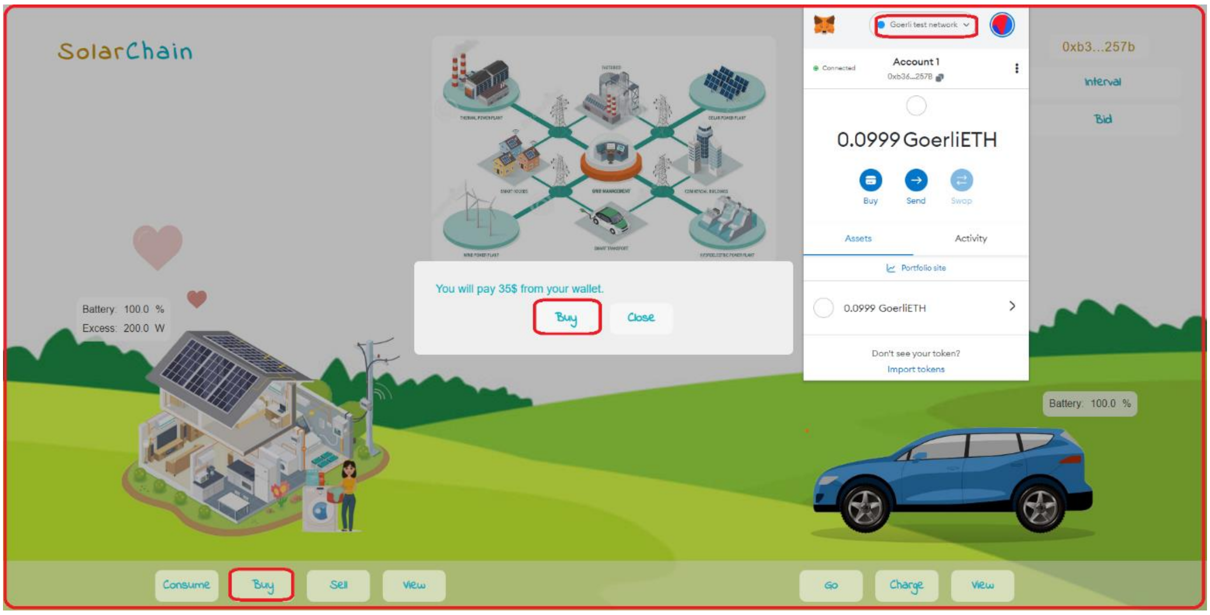



Figure 6. 29 Transaction on P2P market (BUY)

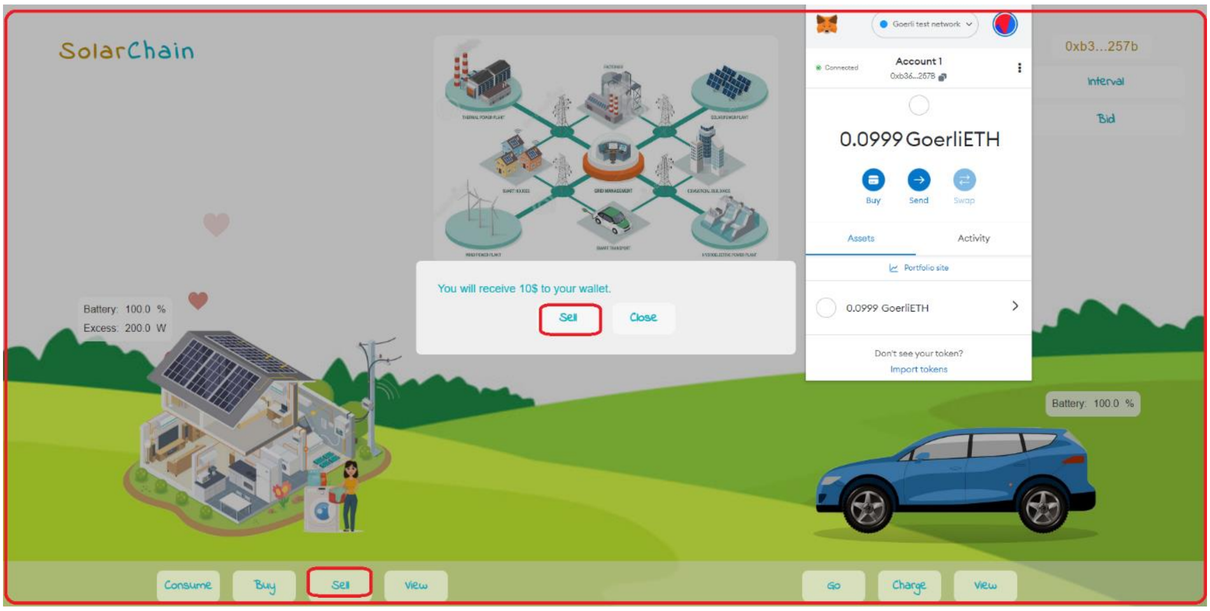



Figure 6. 30 Transaction on P2P market (SELL)

### 6.9.8 Extension of Use Case: Homeowner with Excess Solar Energy in the Post-FiT Era

Expanding upon the pre-Feed-in-Tariff (FiT) era use case involving HomER, a prosumer who has installed solar panels, this extension investigates the situation in the post-FiT era. With the aim of demonstrating the enduring utility and benefits of the Solar Chain Ethereum P2P platform in a context devoid of conventional incentives such as FiTs.

Assumptions and Modifications to the Scenario

The use case takes into account the non-inclusion of FiTs in the economic calculations, which is consistent with the current regulatory framework.

Illustration of a Post-FiT Use Case:

Producing Solar Energy:

The solar panels of the HomER homeowner produce an excess of 10 kWh of electricity on days with ample sunlight. When conventional incentives cease to exist in a post-FiT environment, Solar Chain continues to be a valuable platform for maximising the utilisation of excess energy.

The householder utilises the Solar Chain platform to generate an offer to sell surplus energy. The offer consists of the following details: quantity (10 kWh), pricing (at market-competitive rates), and duration (24 hours). The Solar Chain market is where the offer is published, mirroring the economic realities of a decentralised energy trading ecosystem.

P2P Energy Transfer and Bid Matching: The sophisticated algorithm of the Solar Chain platform matches the homeowner's offer with a nearby consumer in need of electricity. By enabling peer-to-peer energy transfers, the smart contract guarantees the effective utilisation of surplus solar energy.

Real-Time Monitoring and Transparency: The Solar Chain platform enables both the householder and the consumer to monitor energy transfer and consumption in real time. Blockchain technology ensures confidence and openness, thereby bolstering the integrity of the platform.

Intelligent Charging for the householder's EV: Concurrently, the electric vehicle (EV) of the householder is programmed to charge during periods of excess solar energy. By autonomously adjusting the charging rate, the intelligent charging system optimises the utilisation of free solar energy.

Settlement and Savings: Settlement is initiated by the smart contract at the conclusion of the 24-hour period. A debit is made from the homeowner's account in accordance with the energy consumed, while any surplus energy is compensated for. The reduced energy costs experienced by both parties in comparison to standard utility rates demonstrate the platform's ongoing economic benefits in the era following FiT.

This expanded use case underscores the adaptability and resilience of the platform, thereby reaffirming its pertinence amidst changing regulatory environments, all while maintaining the economic advantages for participants.

## 6.10 Discussion

In this Research, *SolarChain*, is a proposed blockchain model for storing and accessing P2P transaction in a secure manner. This study demonstrates an experimental blockchain platform developed on Ethereum that is being implemented to exchange electricity. The demonstration replicates a P2P network, including microgrids, solar-powered homes, and Vehicle-to-Grid (V2G) user nodes. User cases for P2P trading, smart contracts, tracking buyer-and-seller exchanges, and comprehensive implementation process information are all included in the implementation. Using smart contracts, the Solar Chain Ethereum P2P platform enables and governs energy trading. Smart contracts are contracts whose provisions are encoded in computer code and automatically execute. These contracts manage various aspects of energy trading within the context of Solar Chain, assuring transparency, security, and automation.The Ethereum blockchain stores all transaction data, including bidding, matches, energy transfers, and payments. This ledger assures transparency and immutability, thereby preventing fraud and controversies. Tokenization of Energy: Solar Chain represents energy units with blockchain tokens (such as Ethereum's native token, Ether). As energy is exchanged, these tokens are transmitted between users' wallets. Smart contracts automate the procedure of transfer. Automatic Settlement: Smart contracts initiate automatic settlement when a bid duration expires or a predefined condition is met. According to the amount of energy consumed, funds are transferred from consumers to producers, and any remaining energy tokens are returned. The response status in the Solar Chain Ethereum P2P network, within the framework of current research and development, is being examined.

According to refs [96, 109, 181,] highlight how decentralised systems can improve grid resilience, lower transmission losses, and allow for active user participation. The P2P simulation advances our knowledge of how decentralised energy systems can function in actual situations by simulating user interactions in a solar energy network. The Auto Process Bidding Module is both a technological advance in the Solar Chain Application and a continuation of prior research in sustainable energy, decentralised systems, and user-centric design. The ongoing development of the module will rely heavily on its interdisciplinary influences and the potential for collaborative research opportunities. These factors will play a crucial role in determining the future direction of decentralised energy management. Also, the Auto Process Bidding Module is a significant addition to the developing field of decentralised energy systems. The module aims to enhance users' capabilities, optimise energy distribution, and support the overall sustainability goals of the Solar Chain Application and similar projects by combining knowledge from existing research and development. Continual research and development in this field are crucial for improving the technology, tackling obstacles, and enhancing the overall comprehension of decentralised energy management.

Smart Contracts for Energy Trading: A notable development in the use of blockchain technology for energy trading is the incorporation of smart contracts into the Solar Chain Ethereum P2P network. The authors in refs [24, 75, 95] conducted in this field demonstrate how smart contracts can protect and automate energy transactions, cutting down on human error and administrative expenses. The practical implementation of blockchain in maximising peer-to-peer energy exchanges is demonstrated by the usage of Ethereum's restrictions and the demonstration of energy trading methods. In this research, incorporating Truffle into the Solar Chain Application is a deliberate decision that aligns with recognised methodologies for developing Ethereum smart contracts. Truffle is a widely used development framework that simplifies the process of designing, testing, and deploying smart contracts. This is consistent with previous studies in the field of blockchain development, where frameworks such as Truffle are acknowledged for their effectiveness in improving the efficiency and dependability of smart contract deployment. The specified characteristics of the smart contract, such as the implementation of smart grid dynamic pricing, interval bidding, autonomous transactions, and avoidance of double sale, showcase a sophisticated comprehension of the intricacies involved in energy trading inside microgrids. These characteristics are in line with current studies on the incorporation of blockchain and smart contracts to optimise energy markets, improve transparency, and deter fraudulent actions.

Integration of Renewable Energy with Electric Vehicles (EVs): The SolarChain experiment highlights the potential contribution of EVs to overall energy efficiency and grid reliability. Previous research has investigated Vehicle-to-Grid (V2G) as a way to improve grid stability and take use of the demand flexibility for EVs. By incorporating EVs into a peer-to-peer energy trading platform, SolarChain expands on this idea by showcasing how EVs may serve as both dispersed energy resources and grid management tools. arch deficiencies in the architecture of blockchain and its integration with electric vehicle charging:

The research on the Solar Chain Application has discovered notable deficiencies, specifically in the development of the blockchain's operational structure with the incorporation of Electric Vehicle (EV) charging in the P2P energy network. An analysis of the current literature highlights crucial topics that necessitate additional investigation and advancement [24].

Insufficient regard for the extent of battery discharge in calculations of the battery's current energy level: The authors emphasise a significant deficiency in the research, particularly regarding the inclusion of the depth of discharge in the calculations of the vehicle's State-of-Charge. The research on defining the Status-of-Charge lacks a complete strategy that considers the depth of discharge as a significant element. Failure to provide this information may result in an inadequate comprehension of the battery's overall performance and, consequently, affect the precision of the State-of-Charge calculations.

Market Clearing Price (MCP) for Trade in Efficient Energy:

The authors [24, 75] lack the MCP for trading in efficient, the author in ref [183]noted that the day-ahead energy market operates electricity, gas and heating networks (EGHNs) with flexible energy hubs (EHs) using the market clearing pricing (MCP) methodology. Two-level optimisation. Higher-level EHs participate in the market and maximise profits within the operational model of power sources, storage devices, and responsive loads in the form of EHs and their flexibility limit. The MCP model estimates energy price and assesses EH performance's effects on networks' technical and economic indices in the lower-level problem. Optimising network power flow lowers centralised generator running costs.The Solar Chain P2P network's Market Clearing Price (MCP) approach is consistent with studies on effective energy market mechanisms. A crucial component of sustainable energy systems is guaranteeing equitable, effective, and responsive energy trade. The MCP concept, which recalls ideas from previous studies on market dynamics, enables users to actively engage in a dynamic energy market, promoting sustainability and cost savings. Peak Demand Reduction and Financial Incentives: The significance of peak demand reduction for grid stability and efficiency has been repeatedly highlighted in research. In addition to lowering peak demand, SolarChain's integration of PV and V2G energy offers financial incentives to EV customers and PV owners. This is consistent with studies on the possible financial advantages of distributed energy resources and how they might help create a more responsive and robust energy system.

User-Centric Energy Trading: According to the research, the goal of the SolarChain trading system is to make energy trading more user-centric. An awareness of user behaviour and preferences is reflected in the P2P trading user cases, the graphical user interface for tracking trade activity, and the option to set unique phrases for bids. This user-centric methodology is consistent with research supporting open, transparent, and end-user-focused systems.

Remote Monitoring and EV as a Service (EVaaS): Using the Electric Vehicle as a Service (EVaaS) architecture, the study presents the idea of remotely monitoring energy trading operations. This strategy makes use of electric vehicles' potential as assets in energy trading in addition to their transportation capabilities. Similar ideas have been studied in previous studies, which have highlighted the diverse roles that electric cars can play in promoting sustainable energy practices.

Blockchain Ledger and Tokenization for Transparency: The Solar Chain Ethereum P2P platform's tokenization of energy units is in line with the larger trend of using blockchain to improve energy transaction transparency and traceability. The potential of blockchain ledgers to provide an unchangeable record of transactions, stop fraud, and guarantee data integrity has been investigated in research. The integrity of P2P energy trading is enhanced by Solar Chain's use of blockchain technology to store all transaction data, including bidding, matches, energy transfers, and payments. This provides an additional layer of security and transparency.

Reduction of Carbon Emissions and Renewable Energy Mix: As SolarChain has shown, integrating solar power into peer-to-peer energy trading helps to reduce carbon emissions and encourage a more sustainable energy mix. Studies already conducted stress how crucial it is to integrate renewable energy sources into the grid in order to address climate change issues. SolarChain's capacity to plan the best use of energy generated by residential solar systems is in line with the overarching objective of reaching environmental sustainability, lowering dependency on fossil fuels, and raising the proportion of renewable energy in the national grid.

Behavioural Economics in Energy Trading: SolarChain acknowledges the influence of human behaviour on energy trading and has taken into account behavioural economics concepts, such as letting users specify unique conditions for their bids. System adoption is more likely to be effective when it is adaptable and user-friendly, according to behavioural economics research. The user-centric design of SolarChain, which draws inspiration from behavioural economics, advances our knowledge of how to motivate and engage users in the context of peer-to-peer energy trading platforms.

Prospects for Collaborative Research: The Solar Chain Application offers prospects for collaborative research due to its distinct amalgamation of P2P simulation, Auto Process Bidding Module, and blockchain integration. Involving stakeholders, such as academics, business leaders, and legislators, could improve knowledge of the practical applications of decentralised energy systems. Research collaborations could investigate issues of scalability, regulations, and societal effects in order to guarantee a thorough assessment of the Solar Chain model in relation to the broader energy environment.

Possibility of Financial Gain and Economic Benefits: The study emphasises the possibility of financial gain via the SolarChain platform, which allows prosumers to sell extra electricity to other customers or charging stations. This financial incentive is consistent with previous research on the financial advantages of decentralised energy systems. By showcasing how surplus energy may be made profitable, SolarChain advances knowledge about how peer-to-peer energy trading can give users financial opportunities and build a more robust and financially sustainable energy environment.

In summary, the Solar Chain Application is a product of technological innovation, but it also has strong roots in and contributes to the larger field of user-centric design, blockchain technology, behavioural economics, and decentralised energy systems research and development. Solar Chain exhibits its capacity to impact the energy industry's course towards sustainability, transparency, and user empowerment by taking these contextual factors into account. Realising the full societal benefit of such novel energy management systems will require continued research and cooperative efforts. Also, the Solar Chain Application advances the current conversation on decentralised energy management, smart contracts, renewable energy integration, market mechanisms, and user-centric energy trading with its P2P simulation, Auto Process Bidding Module, and integration of blockchain and EV technologies. Through its adherence to established principles and grounded development in current research, Solar Chain exemplifies a creative and pragmatic approach towards influencing the trajectory of sustainable energy systems.

Smart contracts automate energy trading procedures, thereby reducing administrative costs and human error. All transaction information is recorded on the blockchain, ensuring transparency and user confidence. The cryptographic security of Blockchain protects sensitive data and prevents unauthorised access. Peer-to-peer trading obviates the need for intermediaries, thereby reducing transaction costs for users. Users can define custom terms for their bids, nurturing a marketplace that is diverse and competitive. Optimised pairing encourages the use of renewable energy sources, thereby reducing carbon emissions. Smart contracts provide the automation and security necessary for an efficient, transparent, and sustainable peer-to-peer energy exchange.

The user interface (UI) provides 10 default smart contract buttons that users can utilise to run the simulation. The research also looks at the use case for Ethereum's constraints in the application at hand. P2P platforms can lower infrastructure and transmission costs by promoting local energy purchases.

The experiment of *SolarChain* presented that electric vehicles are particularly useful contributors to the reliability of the electric grid because of their potential to both perform grid management services and function as distributed energy resources. The flexible nature of EV demand has the potential to improve grid efficiency by reducing the number of variable energy supplies that are now being cut due to a lack of concurrent demand. *SolarChain* can schedule the proper utilization of energy produced by the solar system of homeowners. The integration of solar power in P2P energy trading increases the renewable energy mix in the national grid and also provides green energy for vehicle charging, which ultimately contributes to the reduction of the net emission of carbon.  The integration of solar power for EV charging also helps in the reduction of peak demand and benefits to solar-powered prosumers. In the event that a prosumer generates a significant amount of solar energy, in *SolarChain* the extra energy is either sold to the grid or to an EV user who is willing to purchase the extra power. In *SolarChain*, the prosumer also has to bid against other bidders for the chance to sell their excess energy to EV users.

Using a graphical user interface, an energy trading prototype is created by authors [162] to remotely monitor energy trading activity between prosumers and consumers. The model chooses the best possible prosumers to satisfy consumer demand by utilizing the electric vehicle as a service (EVaaS) framework as its foundation. The application server can be accessed remotely by the key players so that they can choose between the consumer and prosumer modes. Consumers will have the ability to select their energy demand as well as their location, while prosumers will have the ability to set their available energy as well as their running costs and location. Using the *SolarChain* trading system, prosumers who have solar panels installed in their homes can sell any excess electricity to charging stations. At the same time, the person who owns the electric vehicle is equipped with a digital wallet that can be used to make payments.

The Market Clearing Price (MCP) is a key component of the Solar Chain P2P network, assuring that energy trading is efficient, fair, and responsive to market conditions. It enables users to participate actively in a dynamic energy market, while fostering sustainability and cost savings.

In the next step, we find the peak demand of our local grid, then the power from PV has been integrated into the grid, this shows a clear reduction in the peak demand curve. However, the integration of PV along with V2G energy in our simulated grid shows a very significant reduction in peak demand at the grid. The results show that *SolarChain* not only reduces the peak demand but also gives the opportunity to PV owners and EVs to participate for financial gain.

Energy Demand and Response Status

In the Solar Chain Ethereum P2P network, the status of energy demand and response varies at various intervals based on user behaviour, atmospheric conditions, and time of day. The platform's smart contracts and real-time monitoring are integral to the management of this dynamic energy ecosystem. Here is an overview of the management of energy demand and response:

Real-Time Monitoring

The Solar Chain platform continuously monitors real-time energy demand and generation. Installed at user locations, smart metres provide real-time information on energy consumption and generation. This real-time monitoring enables the platform to quickly adapt to altering conditions.

Daily Intervals

Morning Peak (6:00 AM - 9:00 AM): Typically, energy demand increases in the morning as consumers awaken and begin their daily activities. The intelligent contracts of Solar Chain optimise energy distribution during this period, ensuring that sufficient surplus energy from prosumers is available to satisfy the rising demand. During the daylight hours (9 AM to 4 PM), solar energy production is typically at its zenith. Prosumers with solar panels produce excess energy that is made available to network consumers. During this time, energy prices may be reduced to encourage the use of renewable energy. Evening Peak (four o'clock p.m. to eight o'clock p.m.): As the sun sets, solar energy production decreases, resulting in increased grid demand. During this prime period, Solar Chain may adjust prices to reflect the increased demand and promote energy conservation. Night (8:00 PM - 6:00 AM): With reduced solar generation, the majority of energy demand is met by batteries or grid-supplied electricity. During off-peak hours, prosumers can charge their batteries to prepare for the following day.

Seasonal Differences

Energy demand and response also fluctuate seasonally. During the summer months, increased solar energy production is a result of extended daylight hours. Solar Chain may encourage the utilisation of excess solar energy to charge electric vehicles or store excess energy in batteries. In contrast, the reduced days of winter may increase reliance on grid electricity.

Behaviour and Preferences of Users

Solar Chain takes user preferences and behaviour patterns into account. For instance, some users may prefer to schedule energy-intensive duties during periods of low pricing, while others may prioritise using clean energy sources. The adaptability of the platform enables users to modify their energy consumption and react to fluctuating prices.

Critical Conditions

In emergency situations, such as power disruptions or extreme weather, Solar Chain is able to prioritise energy requirements. Smart contracts can allocate energy to essential services automatically, assuring the safety and wellbeing of users.

Predictive and Forecasting Analytics

Solar Chain integrates weather forecasting and predictive analytics to improve energy demand and response management. The platform optimises energy distribution and pricing by predicting demand patterns and forecasting renewable energy generation.

Finally, the energy demand and response status within the Solar Chain P2P network is a dynamic and adaptable process. Solar Chain seeks to provide its users with a reliable and sustainable energy ecosystem through real-time monitoring, interval-based optimisation, seasonal considerations, user preferences, and emergency protocols.

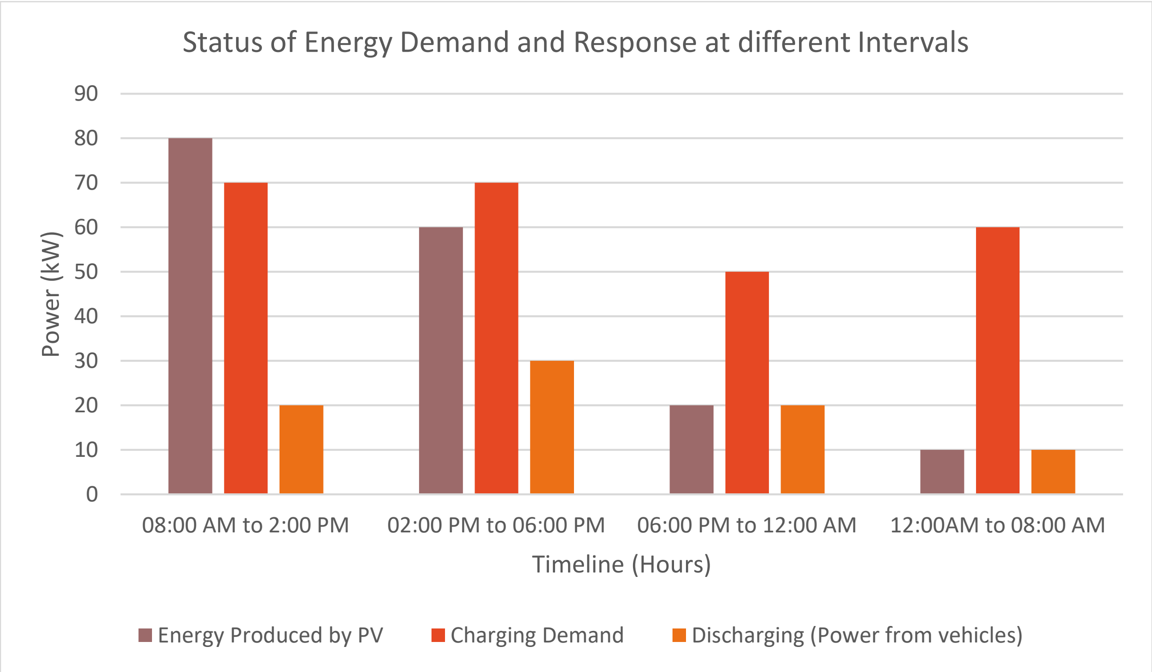



Figure 6. 31 Status of Energy Demand and Response at different intervals

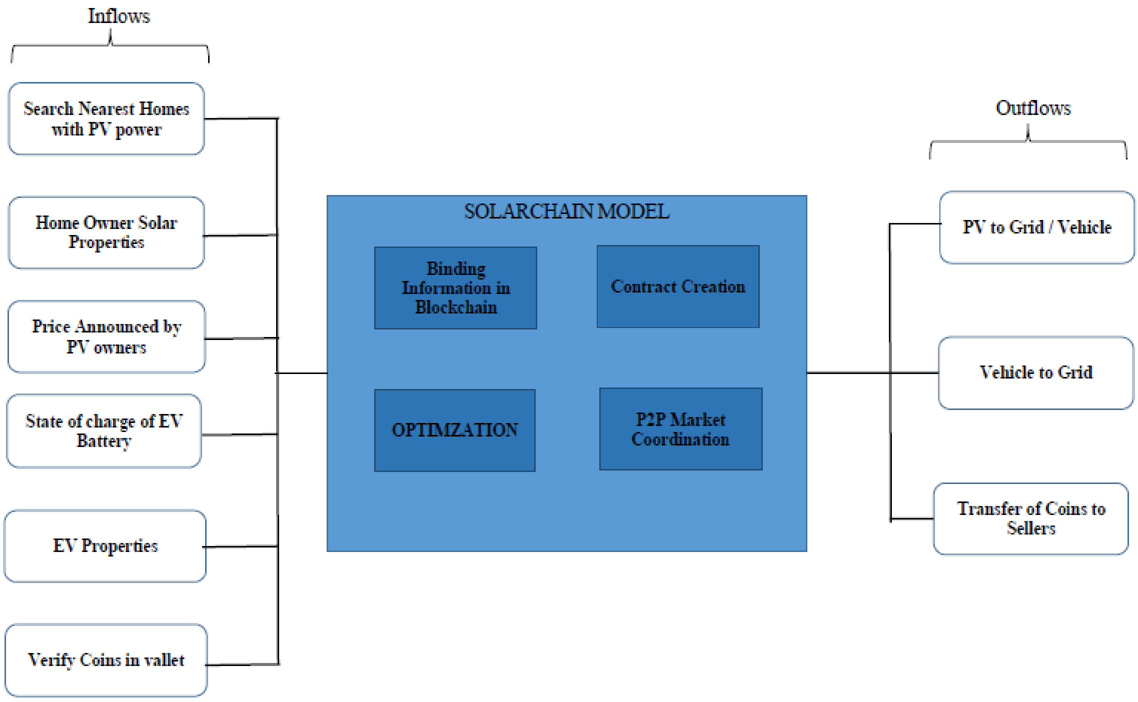



Figure 6. 32 The above figure shows the important output and input values in the completion of P2P energy trading.

### 6.10.1 Benchmark

In this section, the proposed blockchain based P2P energy trading is evaluated in terms of performance, auto bidding strategies and Users experience. The UI allows users to execute the simulation with 10 smart contracts. Front end users simulation (vitual consumers and prosumers generated from benchmarking. The total transaction throughput, System user interface (UI) and overall system performance of the proposed scheme is compared to existing work like Atif Iqbal et al [184] proposed EV energy trading model showing high speed and less computational time. Zhang et al [185] Saxena et al [24] Pipattanasomporn et al [75]. This project presents an initial proof of concept for exchange of solar energy. It defines participants, assets, and transactions using Hyperledger fabric blockchain framework. Our proposed model used an Ethereum-based prototype blockchain network for electricity energy exchange. This demo simulates the power supply P2P network. Micro Grid, homeowners, and Vehicle-to-Grid (V2G) user nodes make up a project. The blockchain-based network for tracking buyer and seller output exchanges, smart contracts, P2P trading user cases, and implementation are detailed. The comparison of centralized vs Decentralized P2P systems is taken into account.

Centralised systems frequently fall under regulatory scrutiny and are required to adhere to compliance standards. The central authority has the power to enact laws, guarantee market stability, and deal with problems like fraud and market manipulation. While Decentralised systems do away with the need for middlemen, cutting expenses and any potential biases they might impose. Peer-to-peer interactions between participants are possible.

A case study of a permissioned blockchain system has been presented by Saxena et al [160]. The suggested system is created utilizing Hyper Ledger Fabric, a permissioned blockchain development platform that permits the segregation of peers into private channels inside a blockchain network. There is greater data privacy for the peers as a result of the fact that each channel has its own distinct ledger and smart contracts, and the data stored on each channel's ledger is kept secret from the data stored on other channels. In this strategy, each homeowner's bidding preferences are set up by the authors as a helpful or selfish bidder. As a result, helpful bidders are given the ability to adjust their schedules in order to lessen peak demand. The proposed system is tested by running simulations on an 8-home neighbourhood using data taken from the actual world. During these simulations, the execution time of smart contracts is measured and compared to industry standards. The suggested solution reduces peak demand by up to 48 kW (62%), according to simulation data, which results in distribution system savings of $1.02 million on average. However, V2G trading is not considered in this project. The approach used by the authors is in the greater favour of utility companies and reduces peak demand. The strategy that was utilized by the authors resulted in a reduction in peak demand while also being more favorable to utility providers. In contrast to this, *SolarChain* is not only balancing the load on the grid but also adopting a user-centric approach to get the benefits in trading. The focus of the authors is on the benchmarking of the execution time of smart contracts. However, emphasis is not given to real-time bidding strategies and V2G energy trading.

A centralised energy system is a well-established and traditional approach for energy generation, delivery, and consumption. Energy production in this system is concentrated in a few number of large-scale power facilities, which frequently use fossil fuels, nuclear power, or renewable sources. The generated electricity is then distributed to other areas and cities via a network of high-voltage power lines. Finally, it is delivered to end customers including households, businesses, and industries via local distribution networks. In contrast, a decentralised P2P energy trading system provides a more current and innovative method to energy trade and distribution. It enables direct peer-to-peer energy transactions by leveraging modern technologies such as blockchain, smart contracts, and distributed energy resources (DERs).

Table 24 Table for centralized and Decentrailzed P2P

| Feature | Centralized system | P2P blockchain based |
|---|---|---|
| **Power Management** | Managed by a central Authority | Managed by Presumers |
| **Efficiency** | Can be inefficient | Can be more efficient |
| **Transparency** | Not very transparent | More transparent |
| **Fairness** | May not be fair to all P2P users | Can be fair to all P2P user |
| **Flexibility** | Limited Flexibility | Energy Flexibility |

### 6.11 Summary

In this chapter, we set out to design and implement Solar Chain, a blockchain-based infrastructure for peer-to-peer energy trading. The primary goals were to create a decentralised network that facilitates the seamless exchange of energy between participants, to evaluate the project's end-to-end implementation, and to establish the Ethereum development environment. Throughout the chapter, we examined various facets of this innovative endeavour; here, we summarise our most important findings and accomplishments.

Design of the Blockchain-based Platform: This chapter began with the meticulous design of the Solar Chain platform. This involved delineating the required architecture, smart contract logic, and data structures for a secure and efficient peer-to-peer energy trading system. Implementation of Energy Trading Between Peer-to-peer: On the basis of the design, we implemented Solar Chain. This entailed the actual engineering and development of the platform, the integration of the designed smart contracts, and the development of the necessary infrastructure for peer-to-peer energy trading. End-to-End P2P Network Testing: Comprehensive testing of the peer-to-peer network was a crucial phase of our endeavour. All

Solar Chain platform components, functionalities, and interactions were subjected to exhaustive testing to ensure their robustness and dependability. Creating an Ethereum Development Environment: In order for Solar Chain to operate on the Ethereum blockchain, a suitable development environment had to be established. To enable our decentralised application, this involved configuring Ethereum nodes, managing wallets, and securing the network. Simulation of Solar Chain Application P2P: To evaluate the efficacy and scalability of the Solar Chain application, we replicated real-world scenarios and conducted a simulation. This phase was crucial for evaluating the platform's ability to accommodate varying levels of demand and user interactions. Simulated P2P User Interface: As the user interface is essential for any blockchain-based application, we simulated the Solar Chain user experience. This required the development of user-friendly interfaces to facilitate peer-to-peer energy trading.

Chapter 6 represents a turning point in our process to develop Solar Chain, a blockchain-based peer-to-peer energy trading platform. We transitioned successfully from design to implementation, rigorously tested the platform, established a robust Ethereum development environment, and simulated user interactions. These achievements bring us closer to realising the vision of a sustainable, decentralised energy trading ecosystem in which users can exchange energy resources directly and contribute to a cleaner, more effective energy landscape. This chapter's insights and accomplishments pave the way for Solar Chain's future periods of development and deployment, representing a significant step forward in its evolution.

# CHAPTER 7 Conclusion and future works

In conclusion, this study has explored the domain of decentralised energy trading, utilising the Ethereum blockchain as a fundamental technology for enabling P2P energy transactions. Homer modelling and optimisation in real-world scenarios A and B provides vital insights into distributed energy resource planning and management. These insights aim to improve P2P energy trading's efficiency, sustainability, and resilience, creating a more decentralised and ecologically friendly energy landscape. The inquiry has produced a number of noteworthy results and contributions:

The implementation of the *SolarChain* platform, which is built on blockchain technology, has made a significant and influential contribution. The platform functions as a reliable and effective channel for residences that possess solar photovoltaic (PV) systems, electric vehicles (EVs), and microgrids to actively participate in P2P energy trading. This platform facilitates the exploration of novel approaches to sustainable energy practises through the promotion of self-sufficiency and the optimisation of resource utilisation. This thesis demonstrates the Implements a peer-to-peer blockchain renewable energy trading platform using Ethereum open-source. The aim of this paper is to provide design and implement a blockchain-based energy trading platform for maximizing EV and PV renewable energy Usage and minimising the daily cost of household electricity consumption. In a real-world project named "Solar Chain network". As a result, this research is to provide technical details describing how a blockchain-based energy trading platform for exchanging solar PV and EV output is designed, developed, and implemented. Blockchain can be use as a data store, a transaction mechanism, a computing platform and also digital assets.

The comprehensive examination of the technological capabilities of the Ethereum blockchain, along with the formulation of an Agile blockchain methodology specifically designed for Ethereum and smart contract development, establishes a foundation for the implementation of resilient and secure decentralised energy trading. The aforementioned statement highlights the capacity of blockchain technology to effectively cater to practical energy-related scenarios.

The research presented in this study demonstrates the possibility for economically and technically optimised energy system designs through the utilisation of modern modelling and optimisation approaches, specifically the Hybrid Optimisation of Multiple Energy Resources

(HOMER). Optimisation plays a crucial role in ensuring the efficient use of resources and cost-effectiveness in decentralised energy systems.

The complex issue of multi-objective optimisation in household appliance scheduling for P2P trade platforms represents a notable advancement in promoting energy efficiency. The technology enables prosumers to effectively reduce their electricity costs through active engagement in decentralised energy marketplaces.

Comparative Analysis of Model A and Model B: The comparative examination of Model A, which incorporates grid connection, solar power, and battery storage, and Model B, which includes grid connection, solar power, electric vehicle (EV) charging, and battery storage, has yielded significant reductions in utility bills and enhancements in efficiency. The computational improvements and cost-effectiveness of Model B indicate the possibility for improved decentralised energy systems.

## 7.1 Summary of Research

The present study has conducted an extensive investigation into several decentralised energy trading methods, focusing primarily on the utilisation of the Ethereum blockchain technology. The creation of the *SolarChain* platform has led to a notable contribution, enabling families equipped with solar PV systems, electric vehicles (EVs), and microgrids to actively engage in P2P energy transactions. The comprehensive examination of the Ethereum blockchain, in conjunction with the implementation of an Agile blockchain development approach, has established a foundation for the establishment of a secure and resilient decentralised energy trading system. The utilisation of modelling and optimisation methodologies, such as HOMER, underscores the capacity for economically viable and technically optimised energy system arrangements. Moreover, the present work investigates the intricate undertaking of multi-objective optimisation pertaining to the scheduling of household appliances. This involves the harmonisation of energy consumption patterns with the preferences of prosumers, while simultaneously aiming to minimise power prices.

The comparison analysis conducted between Model A and Model B demonstrates the significant cost reductions on utility bills and efficiency enhancements that may be attained through the implementation of decentralised energy systems.

This study contributes to the knowledge and implementation of decentralised energy trading, while simultaneously advocating for sustainable and resilient energy practises. It provides insight into a potential future where households actively participate in shaping and optimising their energy environments.

## 7.2 Limitation

Although the SolarChain Ethereum P2P technology shows potential for decentralised energy trading, it is important to recognise its limits. The limitations may affect the thorough assessment and execution of the system:

Electricity generation values on a quarterly basis:

Utilising quarterly power generation values in HOMER simulations imposes a constraint on precision. The quarterly data's level of detail may not precisely match the ever-changing energy supply and demand, which could result in inconsistencies in simulation results.

Validation constraints:

The validation of the platform is hindered by time restrictions as well as technical limitations. Given these limitations, it was not possible to carry out a thorough validation process to determine the platform's effectiveness in real-world scenarios and its compliance with stated standards, within the project's constraints.

The Smart Export Guarantee (SEG) Scheme is a severe limitations within the research. While the SEG provides potential financial incentives for exporting renewable energy to the grid, its implementation and efficacy may vary depending on SEG tariff availability and parameters. However, because to the scope of our investigation, we did not explicitly address or analyse the impact of the SEG programme on our research findings. As a result, the absence of SEG considerations may limit the breadth of our findings, particularly when evaluating the economic viability and regulatory implications of renewable energy integration. Future studies should try to incorporate SEG dynamics to provide a more comprehensive understanding of the difficulties and possibilities related with renewable

Collection of User Feedback:

Collecting user feedback is essential for improving and optimising any platform. Regrettably, the collection and analysis of extensive user comments were not accomplished due to time limitations. This constraint hinders the ability to gain comprehensive understanding of user experiences, preferences, and prospective areas for enhancement.

It is crucial to acknowledge these constraints in order to accurately understand the SolarChain P2P platform's abilities. Future iterations and research efforts should focus on overcoming these limitations, thereby enhancing the reliability and sophistication of the decentralised energy trading system.

### 7.3 Further research and development

In this section, we will discuss potential areas for further research and development. The conducted research has established a robust basis for forthcoming endeavours in the field of decentralised energy trading and the implementation of sustainable energy practises.

Future initiatives could prioritise the practical implementation of the *SolarChain* platform and its assimilation into established energy systems. To achieve widespread acceptance, it is imperative to address regulatory and policy considerations. Blockchain Scalability: In light of the scalability difficulties associated with blockchain technology, it is imperative to continue conducting research in order to investigate and execute remedies that can effectively handle a greater volume of participants and transactions within peer-to-peer energy marketplaces. Further investigation can explore more sophisticated optimisation methods, machine learning algorithms, and artificial intelligence-driven methodologies to continuously improve the effectiveness of energy resource utilisation and trading tactics. Artificial intelligence techniques such as machine learning and big data analytics could be used to identify consumer energy patterns, thereby enabling the provision of customised and value-added energy products for demand-side flexibility and energy trading. The promotion of user adoption and the provision of educational resources to families regarding the advantages and complexities of decentralised energy trading are of paramount importance. Subsequent research endeavours may prioritise the development of interfaces that are easily navigable and comprehensible to users, as well as the implementation of instructional programmes. The exploration of blockchain interoperability solutions facilitates effective communication among diverse blockchain networks, hence enhancing the potential for decentralised energy trade at a worldwide level.

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# Appendix

Battery Energy Storage System (BESS) - Lead Acid Battery Storage Boiler - Generic Boiler Converter - Generic Converter

Decentralised applications, sometimes referred to as DApps, are software applications that operate on a decentralised network rather than a centralised server.

A Distribution System Operator (DSO) is an entity responsible for the management and operation of the distribution system within a given area.

Demand Side Management (DSM) refers to the strategic planning and implementation of measures aimed at influencing consumer behaviour and electricity consumption patterns. DSM strategies are designed to optimise the use of energy resources, reduce peak demand, and enhance overall energy efficiency.

Demand response (DR) is a mechanism that allows electricity consumers to adjust their energy consumption patterns in response to changes in electricity prices or grid conditions. By participating in DR programmes, consumers can reduce their electricity usage during

The concept of a decentralised network (DN) refers to a system in which multiple nodes or participants are involved in the distribution and processing of information or resources. In a DN, there is no central authority or single

Energy efficiency, sometimes abbreviated as EE, refers to the practise of using energy in a more efficient and effective manner. It involves minimising energy waste and maximising energy output for a given task or process. Energy efficiency is

The Ethereum Virtual Machine (EVM) is a key component of the Ethereum blockchain platform.

The Feed-in Tariff (FIT) is a policy mechanism that provides financial incentives to individuals or organisations who generate renewable energy and feed it into the electricity grid.

The acronym HOMERS stands for Hybrid Optimisation of Multiple Energy Resources.

Information and Communication Technologies (ICT) refer to a broad range of technologies that facilitate the acquisition, storage, processing, and dissemination of information, as well as the communication and interaction among individuals and organisations.

The Market Clearing Price (MCP) is a term used in economics to refer to the price at which the quantity of a good or service supplied by producers is equal to the quantity demanded by consumers, resulting in a state of market equilibrium.

The acronym OOPS is for Object Oriented Programming Language, which refers to a programming paradigm that emphasises the use of objects and classes for software development. On the other hand, Ofgem stands for the Office of Gas and Electricity Markets, an organisation responsible for regulating and overseeing the gas and electricity markets in a particular jurisdiction.

P2P, which stands for Peer-to-Peer, refers to a decentralised network architecture where participants can directly interact with each other without the need for intermediaries. PoS, or Proof-of-Stake, is a consensus algorithm used in blockchain networks to secure and validate transactions based on the amount of cryptocurrency held by participants. On the other hand,

Photo Voltaic (PV) refers to the technology that converts sunlight into electricity.

The phrase "prosumer" is a technical blend that combines the words "producer" and "consumer." The term "consumer-producer" pertains to an individual or entity that engages in the consumption and production of goods or services, typically within the domains of energy or technology. Prosumers actively engage in the utilisation and creation of products or services, hence eroding the conventional demarcation between consumers and producers.

Renewable energy (RE) refers to energy sources that are naturally replenished, such as solar, wind, and hydroelectric power. These sources are considered sustainable and have gained significant attention in recent years due to their potential to mitigate climate change and reduce reliance on fossil fuels.

Smart contracts (SCs) are self-executing contracts with the terms of the agreement directly

The Smart Grid Architecture Model (SGAM) is a conceptual framework that provides a structured approach for designing and analysing smart grid systems. It offers a comprehensive view of the many components and their interconnections inside a smart grid infrastructure. By utilising the SGAM, researchers and practitioners can better understand the

The concept of SmIGen, which stands for Smaller Genst, refers to the notion of reducing the size or scale of Genst, a term that likely pertains to a larger entity or concept.

The State-of-Charge (SOC) refers to the amount of electrical energy stored in a battery relative to its maximum capacity.

A Transmission System Operator (TSO) is an entity responsible for the operation, control, and maintenance of the transmission system within a certain region or country. The TSO plays a crucial role in ensuring the reliable and secure transmission of electricity from power generators

The concept of V2B, which stands for Vehicle-to-Building, refers to the integration of electric vehicles (EVs) with buildings in order to facilitate the exchange of energy between the two systems. Similarly, V2G, or Vehicle to Grid, involves the utilisation of EVs to supply power to the electrical grid when they are not in use.

The concept of V2H, which stands for Vehicle-to-Home, refers to the ability of electric vehicles to transfer energy from their batteries to power residential homes.

The term "vehicle-to-everything" (V2X) refers to a collection of technologies that allow the energy stored in the battery of an electric vehicle (EV) to be exported and used in a home, by other buildings, or to assist in the balancing of the electricity grid.