Ahmet YAĞMUR

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BLOCKCHAIN-BASED ENERGY APPLICATIONS: DSO PERSPECTIVE

A THESIS
SUBMITTED TO THE DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING AND THE GRADUATE SCHOOL OF ENGINEERING AND SCIENCE OF ABDULLAH GUL UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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M.Sc. thesis titled Blockchain-based Energy Applications: DSO Perspective has been prepared in accordance with the Thesis Writing Guidelines of the Abdullah Gül University, Graduate School of Engineering & Science.

Prepared By
Ahmet YAĞMUR

Advisor
Asst. Prof. Samet TONYALI

Head of the Electrical and Computer Engineering Program
Assoc. Prof. Kutay İÇÖZ

ACCEPTANCE AND APPROVAL

M.Sc. thesis titled Blockchain-based Energy Applications: DSO Perspective and prepared by Ahmet YAĞMUR has been accepted by the jury in the Electrical and Computer Engineering Graduate Program at Abdullah Gül University, Graduate School of Engineering & Science.

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JURY:

Advisor: Asst. Prof. Samet TONYALI

Member Prof. Vehbi Çağrı GÜNGÖR

Member Asst. Prof. Serkan BAHÇECİ

APPROVAL:

The acceptance of this M.Sc. thesis has been approved by the decision of the Abdullah Gül University, Graduate School of Engineering & Science, Executive Board dated ….. /….. / ……….. and numbered …………..……. .

……….. /……….. / ………..

(Date)

Graduate School Dean
Prof. İrfan ALAN

ABSTRACT

BLOCKCHAIN-BASED ENERGY APPLICATIONS: DSO PERSPECTIVE

Ahmet YAĞMUR

MSc. in Electrical and Computer Engineering

Advisor: Asst. Prof. Samet TONYALI

April 2022

This thesis discusses blockchain-based energy applications from the distribution system operator (DSO) perspective. Blockchain has a potential impact on emerging actors, such as electric vehicles (EVs), charging facility units (CFUs), Distributed Energy Resources (DERs) and microgrids of the electricity grid. Although, blockchain offers magnificent, decentralized solutions, owing to the reality of the existing grid structure, the central management of DSOs still plays a significant, non-negligible role. Numerous studies of proposed blockchain-based EV systems have investigated the energy costs of EVs, fast and efficient charging, privacy and security, peer-to-peer energy trading, sharing economy, selection of appropriate location for CFUs, and scheduling. Additionally, blockchain in DERs, microgrids and energy market investigated in literature. However, cooperation with DSO organizations has not been adequately addressed. Blockchain-based solutions mainly suggest an entirely distributed and decentralized approach for energy trading. However, converting the entire power system infrastructure is considerably expensive. Building a thoroughly decentralized electricity network is nearly impossible in a short time, particularly at the national grid level. In this regard, the applicability of the solutions is as significant as their appropriateness, especially from the DSO perspective, and must be examined closely. The blockchain applicability of the essential DSO services such as SCADA and AMI are analyzed in this study. Time series analysis applied to forecast future peak load of the grid in a pilot region. Reducing the peak load by using BC based demand side management mechanism scenario evaluated and total saving of grid investment is analyzed. We searched and analyzed DSO-based requirements for potential blockchain applications in the energy sector.

Keywords: AMI, DERs, DSO Blockchain, EVs, SCADA

ÖZET

ELEKTRİK DAĞITIM ŞİRKETLERİ PERSPEKTİFİNDEN BLOCKCHAIN TEMELLİ ENERJİ UYGULAMALARI

Ahmet YAĞMUR

Elektrik ve Bilgisayar Mühendisliği Anabilim Dalı Yüksek Lisans

Tez Yöneticisi: Dr. Öğr. Üyesi Samet TONYALI

Nisan 2022

Blok zincirin elektrik şebekesinde yeni öne çıkan elektrikli araçlar, elektrikli araç şarj istasyonları, dağıtık enerji üretim kaynakları ve mikro şebekeler gibi katılımcılar üzerinde potansiyel etkileri vardır. Blok zincir merkeziyetsiz muhteşem bir çözüm sunmasına rağmen, şebekenin mevcut yapısı ve elektrik dağıtım şirketinin merkeziyetçi yönetim şekli, elektrik dağıtım şirketinin hala şebeke üzerinde gözardı edilemez görev ve etkileri olduğunu göstermektedir. Literatürde blok zincir tabanlı birçok çalışmada, elektrikli araçlar başta olmak üzere birçok şebeke paydaşı araştırılmıştır. Ancak dağıtım şirketleri ile iş birliği konusu açık ve net şeklide ele alınmamıştır. Blok zincir tabanlı bu çözümler genel olarak tamamen dağıtık ve merkeziyetsiz enerji ticareti yaklaşımı öneriyor, ancak bütün bir elektrik şebekesi sistemini merkeziyetsiz yapıya dönüştürmek oldukça pahalı olacaktır. Ancak yinede elektrik şebekesinin tam anlamı ile merkeziyetsiz olması, özellikle bütün ulusal elektrik şebekesi seviyesinden bakıldığında, kısa vadede neredeyse imkânsızdır. Bu bağlamda, özellikle elektrik dağıtım şirketi perspektifinden bakıldığında, çözümlerin uygulanabilirliği kadar mevcut yapıya uygunluğu da önem arzetmektedir ve daha yakından dikkatle gözden geçirilmelidir. Bu çalışmada, elektrikli araçlar, elektrikli araç şarj üniteleri, dağıtık enerji kaynakları, mikro şebekeler, enerji marketi, elektrik dağıtım şirketlerinin en önemli hizmet araçları olan SCADA ve akıllı sayaçlar için blok zincir uygulanabilirlikleri elektrik dağıtım şirketleri perpetifinden analiz edilmiştir. Ayrıca zaman serileri kullanılarak gelecek dönem puant gücü hesaplanmış ve blockchain temelli talep tarafı yönetimi projesi uygulanırsa elde edilecek tasarruf miktarları analiz edilmiştir.

Anahtar kelimeler: Akıllı Sayaçlar, Dağıtık Enerji Üretim Kaynakları, Elektrik Dağıtım Şirketi ve Blok zincir, Elektrikli Araçlar, SCADA

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LIST OF ABBREVIATIONS

DSO	Distribution System Operator
TSO	Transmission System Operator
BC	Blockchain
SCADA	Supervisory Control and Data Acquisition
AMI	Advanced Measurement Infrastructure
EVs	Electric Vehicles
EVOs	Electric Vehicle Owners
CFUs	Charging Facility Units
CFUOs	Charging Facility Unit Owners
DERs	Distributed Energy Resources
DG	Distributed Generation
RESs	Renewable Energy Sources
PV	Photovoltaic
SG	Smartgrid
P2P	Peer-to-Peer
V2V	Vehicle-to-Vehicle
V2G	Vehicle-to-Grid
M2M	Machine-to-Machine
B2B	Business-to-Business
DR	Demand Response
DSM	Demand Side Management
ESSs	Energy Storage Systems
CAs	Consensus Algorithms
PoW	Proof-of-Work
PoS	Proof-of-Stake
PoWR	Proof-of-Work based on Reputation
PoB	Proof-of-Benefit
ONPoB	Online Benefit Generating PoB
BFT	Byzantine Fault Tolerance
PBFT	Practical Byzantine Fault Tolerance
DBFT	Delegated Byzantine Fault Tolerance
DAG	Directed Acyclic Graph
PoAu	Proof-of-Authority
PoR	Proof-of-Reputation
PoRCH	Proof-of-Random Count in Hashes
LNSM	Neighborhood Search with Memory
ET	Energy Trading
AdBEV	Adaptive Blockchain-based Electric Vehicle Participation
ICT	Information and Communication Technology

OpenADR	Open Automated Demand Response
IoT	Internet-of-Things
ARIMA	Autoregressive Integrated Moving Average

Chapter 1

Introduction

The smart grid (SG) in the context of an electricity grid is one in which all parties act to reach the general aim of a sustainable, economical, and secure electricity supply environment [1-2]. The term "smart grid" includes various grid operations and energy measurement and control units such as smart meters, circuit breakers, load control switches, and other smart appliances. Increments in the usage of Electric Vehicles (EVs), global orientation to low carbon energy solutions (e.g., RESs), and the tendency of sustainable DERs have made SG control and management methods more difficult and complicated than ever. Electricity is a commodity that every user consumes or produces continuously and has the same energy measurement and control methods in different fields. Energy in various areas creates a significant requirement for common agreement on solutions for similar problems. However, electricity usage related to a wide range of sectors has joint tenancy features, and every part of the system affects other parts positively or negatively. Nevertheless, the value of the traded energy and number of grid participants have increased rapidly, and all these changes have created an urgent need for cyber security and greater grid stability. The more intelligent and self-sufficient the grid becomes, the more robust and sustainable it is. Additionally, the natural development and transformation process of grid technologies have resulted in a grid system that is more decentralized every year. Blockchain is one of the most promising solutions for these issues; in terms of realizing SG requirements, it will most likely dominate the entire power grid and make itself a significant part of our daily electric usage routine. In the literature, the distributed structure of blockchain and energy [3-5], particularly distributed energy resources (DERs), electric vehicles (EVs), smart meters, supervisory control and data acquisition (SCADA), marketing operations, and microgrids, as well as possible Blockchain (BC) solutions have been discussed in detail [6].

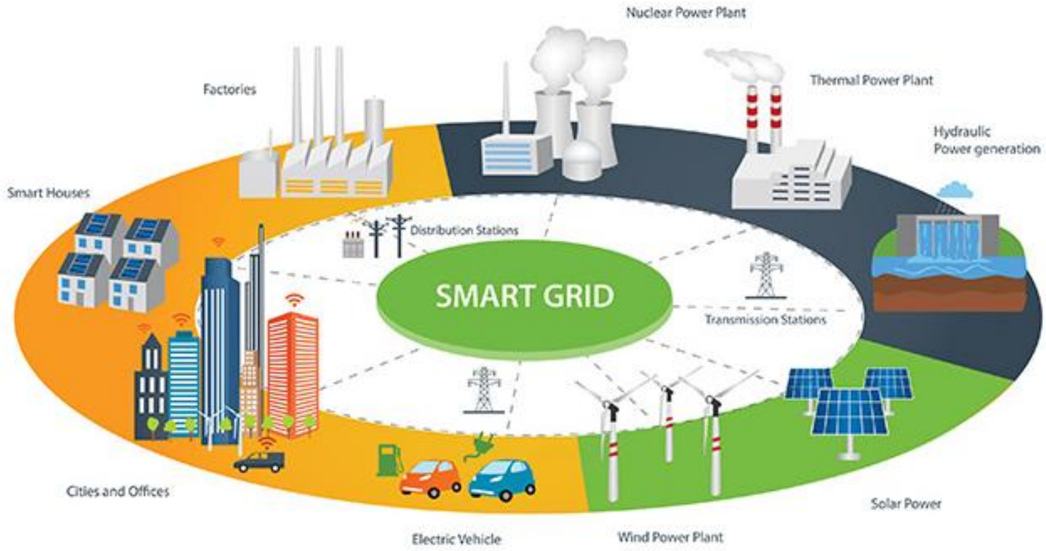

Figure 1.1 The illustration of smart grid environment [141].

BC technology seems relatively mature in the cryptocurrency area but is immature in the energy sector [7]. Local projects of energy blockchain and research on examples focused on one field have been commonly studied, particularly in recent years. Security, privacy concerns, and a wide range of potential aspects of energy blockchain applications on grids, the existence of distributed energy users, and possible local markets in the future seem appropriate for the BC era. However, an essential part of the SG—the distribution system operator (DSO)—is missing [8]. The natural electrical connection of the grid parties and their inevitable relation with DSOs makes a relatively central authority, the DSOs, indispensable in the future. In addition, the existence of DSOs may fuel privacy and security concerns. An illustrastion of smart grid and some part of it is shown in Figure 1.1. Despite the considerable expectation of independent SG from third-party interventions with the help of decentralized BC technology, the role of central grid operators and their compulsory existence should be clarified. Meanwhile, the number of customers, prosumers, and sources of distributed generation (DG) have increased rapidly [9]. Hence, managing the activity of numerous parties and additional marketing operations with only a few sources is a challenging issue. In recent years, the modern world has embarked on a new promising solution, BC. Studies have been conducted of BC and the energy sectors as energy markets, data sharing and security, energy management in SG, information transmission, peer-to-peer (P2P) energy trading in microgrids, and the potential of BC [10-11].

Alonso et al. highlighted some of the problems of DSOs, such as a lack of unity of regulations worldwide, multiple DERs at different voltage levels, deployment of millions of e-mobility solutions, voltage/reactive power management, congestion management problems of smart grids, and the need to improve SCADA abilities [12]. These problems have provoked new concerns and threaten reliability, stability, and network-maintaining quality. In this situation, the DSO faces two main problems: the exponential increment of DERs and their intermittent pattern caused by instant weather changes, and second, the dramatic increase in number of EVs and the effect of their user patterns on the grid. Both these uncertainties and quantitative rapid changes are more likely to strongly affect the operations of DSOs. DSOs have many units to fulfill the compulsory and specific tasks, such as maintenance of the grid, billing of consumed energy, participating in market operations, instant active/reactive load management, and investment to enlarge the grid area and capacity. Nevertheless, some of these areas are well suited to the application of BC technologies, some of which are slightly harder to implement in SGs. For instance, marketing staff, P2P trading, EVs (V2G, V2V, G2V), and billing workload seem appropriate and their problems soluble with BC. Conversely, regarding adapting equipment such as smart meters and SCADA in many countries, the DSOs in charge of maintaining these smart meters/SCADA-related devices find them harder to customize. Xie et al. comprehensively surveyed smart cities under smart citizens, smart healthcare, smart grids, smart transportation, and supply chain management [9]. Although studies suggest an entirely distributed and decentralized approach to energy trading, the power system infrastructure still needs to be managed by DSOs [13]. In many environments, there is no direct connection between consumers and producers [14]. Therefore, there is no choice other than to facilitate existing DSO components in the network. The greatest limitation on rapid changes in the current SG is that the energy flow must still go through the centralized electricity utility network. In this context, despite the centralized structure of DSOs, decentralized solutions are required [15].

More importantly, to the best of our knowledge, one important point is missing or not adequately discussed in current literature. If we consider not the far future but the near future, the BC affordance of the existing structure of the electricity grid is directly related to the DSOs. Many DSO occupations and problems are soluble by incorporating them into the BC. However, future challenges, such as the cost of transformation, appropriateness, and privacy issues, tie DSO’s hands in the face of rapid development.

At first glance, at the national grid level, a thoroughly decentralized electricity network is nearly impossible because of the centralized nature of the DSO and existing grid structure, at least in the near future. However, apart from optimizing these solutions, the transaction cost of the new technology, possible needs for new devices, suitability of existing structure, the resilience of communication substructure, and adequate employee needs are main concerns for the near future [16]. In this regard, the applicability level of the solution is as significant as its appropriateness. Despite these requirements, studies of DSO interactions and their impact on the near future of BC are lacking [17]. In other words, in this case, the issues of the DSOs should be solved through new distributive solutions. However, the economic aspects of the solution and its applicability to BC in the near future, from the DSO perspective, must be investigated extremely closely. In this study, the literature on DSOs and blockchain is investigated, and its convenience or inappropriateness is discussed in the following respects: (i) the responsibilities that DSOs burden; (ii) possible costs of the transition from conventional to more decentralized blockchain-based modern electricity networks; (iii) the applicability of BC to the existing power systems and possible solutions; (iv) the suitability of existing structures of DSOs [18].

Figure 1.2 The well-known Brooklyn Microgrid [142].

BC adoption on energy trading started with the significant Brooklyn experimental study as illustrated in Figure 1.2. The BC solution matches the need of these distributed infrastructures considerably well, despite certain inappropriate and inapplicable aspects. In the modern world, the fulfillment of DSOs' responsibilities is significantly involved in maintaining resilience, stability, and fault detection/elimination systems [19]. However, all transaction details and the user's private data must be secured even from DSOs because of possible malicious manipulations. All these duties can only be conducted with the help of distributed BC technology. Teufel et al. found that social and technical transformation and political decisions, digitalization, have led to major challenges strongly affecting the development of the energy market from conventional to contemporary [20]. The method and speed of the transformation of current power grids are not exactly clear but are foreseeable to some extent [21]. According to the predetermined rules of the smart contract, all parties can be combined to realize trusted trading between peers, ensure grid flexibility and reliability, and equalize all parties' rights [22]. This thesis classifies DSO-level flexibility resources as DERs, demand response (DR), microgrids, energy storage systems (ESSs), market or pricing/tariff-based approaches, and network reconfiguration. Reference [5] offers a smart contract implementation under different blockchain technologies to take advantage of its features in an energy-trading area.

Electricity markets were, until recent decades, technically designed to deduce real-time demand-supply balance and manage the bottlenecks, constraints, and congestion in transmission systems [23]. Conversely, from the beginning of the development of DERs, EVs, and local markets, the aforementioned issues and solutions became the responsibilities of DSOs as well as the transmisson system operators (TSOs). In the near future, DSOs will probably manage the network's optimum power flow and maintain the security of the grid. A comprehensive survey of future SG under the sub-headings AMI, SCADA, energy trading and marketing, EVs and charging unit management, and microgrids has been conducted by the authors; however, the DSO role and BC applicability are lacking [24]. Due to security and privacy concerns, Alladi et al. investigated the applicability of BC in smart grids [25]. Challenges facing BC in SGs are scalability, centralization, development and infrastructure costs, and legal and regulatory support. BC and distributed energy were researched and categorized under technological, economic, social, environmental, and industrial dimensions, and issues of technical and institutional readiness have been thoroughly investigated [26]. However, while some studies have addressed BC and SG applicability, none have investigated the existing situation of DSOs and BC to DSO applicability thoroughly [24-27]. In their study, Wu and Tran organized the features of the energy internet as accurate measurement, wide-area multisource cooperation, smart control, and open trading [28]. Although most of the parts of SG are inseparable and profoundly relevant to each other, they need to be clustered to be clearly understood.

Wide energy trading and bilateral power flow may create feasibility and stability issues. Thus, in the thriving energy sector, the security of supply and grid sustainability must be considered as significant as the cyber-security of the system. Another device intended to be useful, BC development, may eventually demolish and damage the entire system. To avoid these possible detrimental consequences, the DSO and its grid parties (SCADA, AMI) are discussed, and their existence in Blockchain in energy is emphasized. In this era of digitalization, the managing process of digital entities differs from managing physical entities in many aspects. Whensoever all these facts are considered, it seems that the electricity grid's physical manager, the DSO, will most likely retain its substantial and more active role in terms of maximizing the benefits of the majority, overcoming grid congestion, and fulfilling other grid requirements.

1.1 Aims and Contribution of Thesis

In this thesis, the aforementioned situation is discussed, particularly from the perspective of DSOs and the practicability of BC solutions in the not-too-distant future under SCADA, AMI, EVs, DERs, microgrids, marketing, demand response (DR), DSO/TSO interaction, environmentalism, and grid investment topics. Within the context of this thesis, we will investigate and discuss the literature related to the interaction between DSOs, EVOs/CFUs, DERs/RESs, microgrids, and electricity markets with the aid of blockchain technology. Subsequently, we examine the applicability of blockchain in the existing DSOs scheme.

1.2 Outline of Thesis

The rest of this thesis is organized as follows. Chapter 2 sketches the background of blockchain technology, including consensus algorithms and their outstanding features. In Chapter 3, the DSO services required to participate in the blockchain system are discussed. Furthermore, the DSO-related grid parties and their interactions are investigated in detail. In Chapter 4, reducing the peak load by using BC based demand side management mechanism scenario evaluated and total saving of grid investment is analyzed. Chapter 5 briefly gives some information about energy & blockchain applications in Türkiye. Chapter 6 discusses problems and possible solutions, gives future prospect and finally, concludes the thesis.

Chapter 2

Overview of Blockchain

The blockchain is a set of methods which contains cryptographic share of growing ledger database. This protocol enables the computers, which connected to each other via network, to communicate more secure and more decentralized way. In blockchain environment, each block is connected to the next one, and also every block contains a small part of information from the previous block, except for the genesis block. There is no need for an authority to orient transactions or value exchange. It is reliable, distributed and customer friendly from the point of transaction fees.

Blockchain technology is an immutable transaction ledger that allows for a secure and distributed system without the need for a central authority [29]. In blockchain, each transaction is maintained in a block on the network as illustrated in Figure 2.1. A block, like a chain structure, stores the hash value of the previous block. This structure further creates immutability. Blockchain has really wide range of usage area, almost every area which is related to digital information, for instance financial industry, electronic voting, healthcare system, identity, e-commerce, data management, energy, gaming, e-governance, and many more. Only energy related blockchain applications considered in this study.

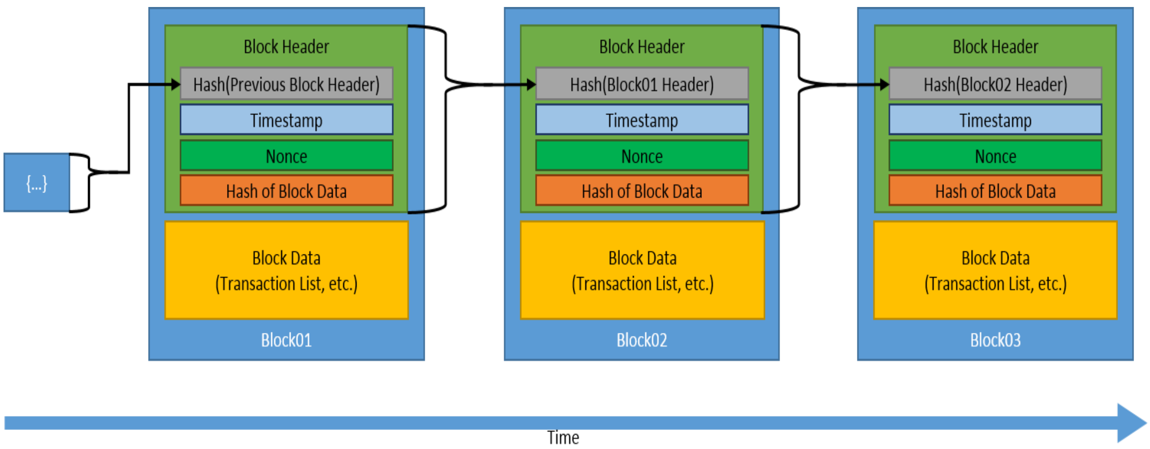

Figure 2.1 Inside of a block and its connection diagram [143].

Each transaction on the blockchain can be stated using cryptographically signed blocks, and transactions are verified by network users [30]. Different consensus algorithms are used by blockchain to verify transactions. Consensus algorithms are agreements among a group of people to validate transactions. The decision is made by majority voting at the end of the verification procedure [31].

2.1 Features of Blockchain

2.1.1 Hash Function

Hash is a function which creates some kind of block signature or digital signature. It uses a cryptographic algorithm (SHA-256) and contains output of a signature algorithm like ECDSA (Eliptic Curve Digital Signiture Algortihm) with users' private key. The output of the hash function is a fixed length of string to identify a piece of data. The working principle of hash function is shown in Figure 2.2.

Figure 2.2 How hashing works [144].

2.1.2 Public & Private Key

Public Key: Public key created by private key to sign every transaction and verify them. Anyone who handles the public key of any user can verify the occured transaction. The data can be signed with private key and created a message and the receiver, or anybody can verify this new transaction hash with the corresponding public key. However, it is computationally infeasible to generate the private key from public key. The illustration of public&private key pair and transaction are shown in Figure 2.3.

Private Key: Only known to the key holder, it is used to sign every transaction of that user. An example of message and how it signed with private key is illustrated in Figure 2.3.

Blind Signature: It is a signature that content of the message encrypted in it and before signed. All parties can verify it publicly against the original one.

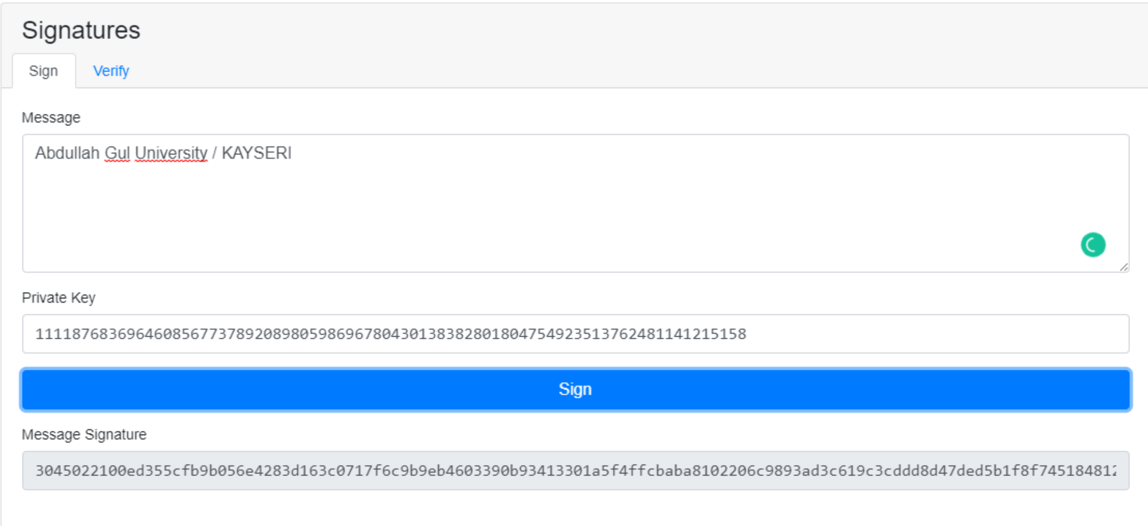

Figure 2.3 Public & Private key pair [145].

2.1.3 Nonce

In blockchain mining procedure miners have to solve a cryptographic puzzle called proof-of-work (PoW). It means process of finding a hash value (nonce) that is lower than predefined target value. If some manupilators try to change the data of each block, they have to redo all mining process again to reach predefined hash target value (the number of zeros in front of the result of hash function) by changing the nonce or data itself. It is nearly impossible to have such computational power to do that computationally intensive process. Every block consists of following elements; a hash pointer of the previous block, timestamp, nonce which is used to vary the value of the hash and list of transactions, hash of the block itself. An example of nonce in blocks and connection of each block with next one are illustrated in Figure 2.4.

2.1.4 Smart Contract

Smart contracts are another important component of many blockchains and distributed ledger platforms. It is some king of digital contract which contains terms, agreement conditions between the peers. A smart contract is a set of rules executed on a blockchain. As the software representative of users, it automatically accomplishes specific obligations and tasks when proper conditions occur. Smart contracts are used to handle data, contracts, and relationships and provide functionalities to other contracts and

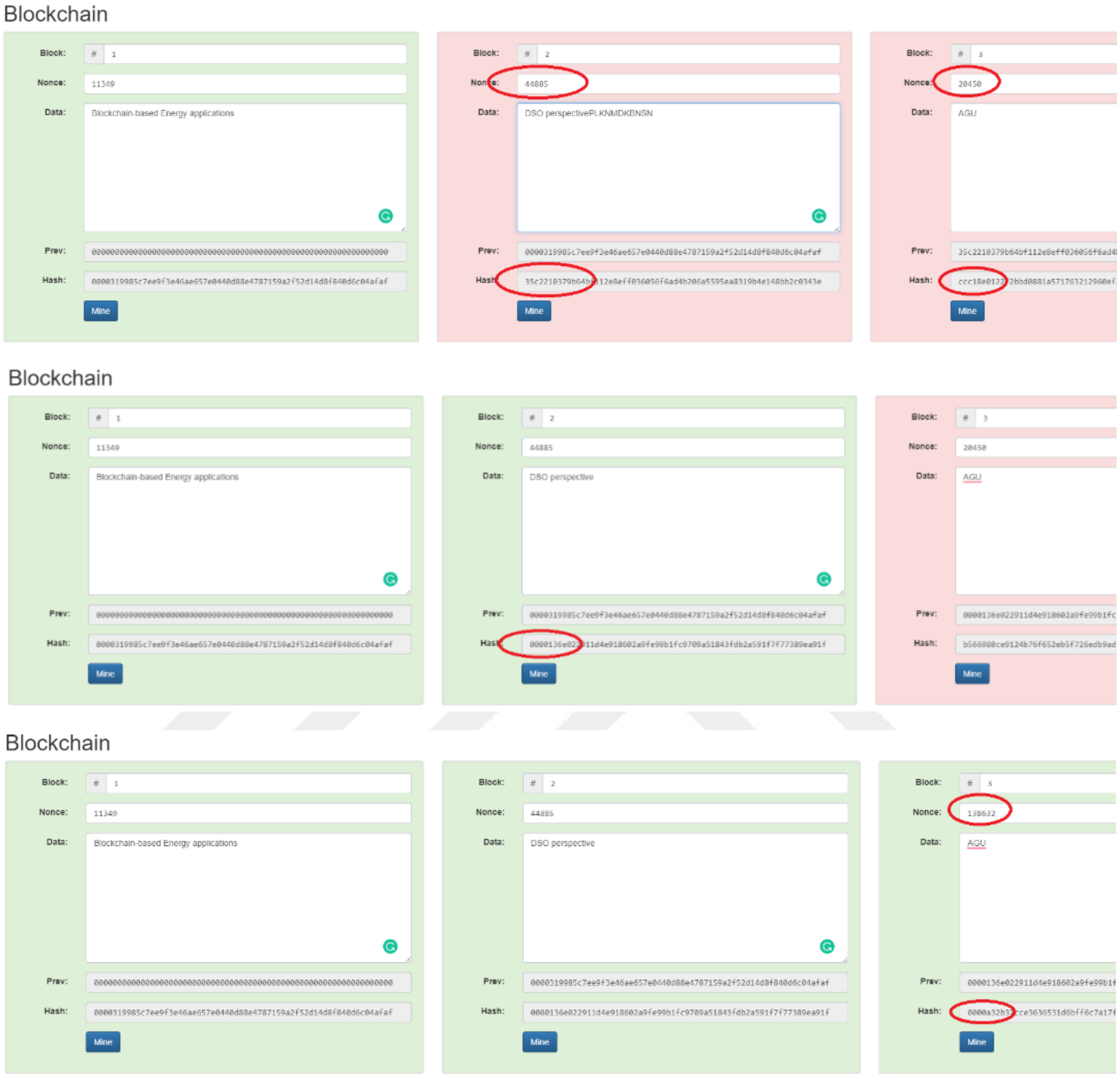

Figure 2.4 Nonce and blockchain immutability [146].

complicated authentication [32-33]. Autonomy, trust, backup and accuracy features of smart contracts are illustrated in Figure 2.5. Also, working principle of smart contracts is illustrated in Figure 2.6.

2.1.5 Merkle Tree

Merkle tree is some kind of main part of the blockchain technology. It contains a mathematical data structure of different hashes of the blocks. It serves as a summary of all transactions. It means there is no need to download all transactions to verify them. Only the hashes of the block's header are enough. It works like hashing nodes hierarchically and transferring child nodes' data (hash value) through upper nodes and lastly in to the block.

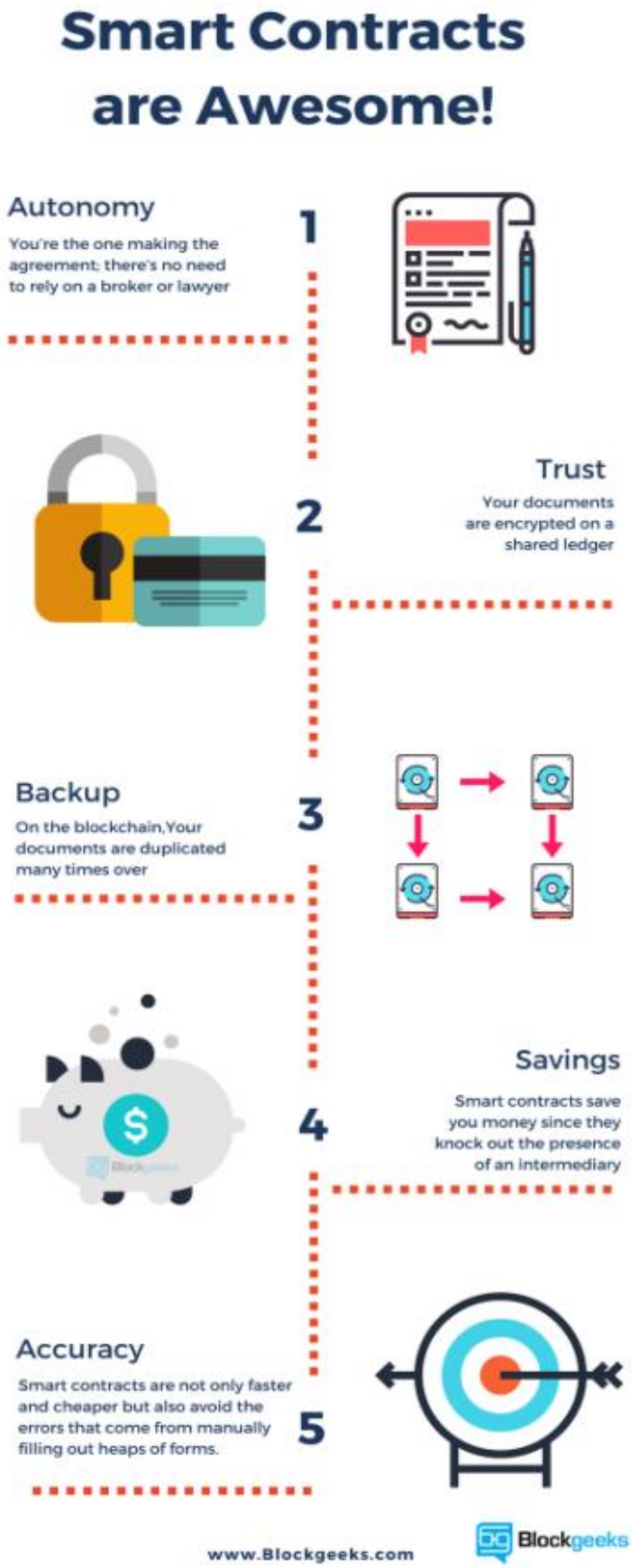

Figure 2.5 Smart contract flowchart [147].

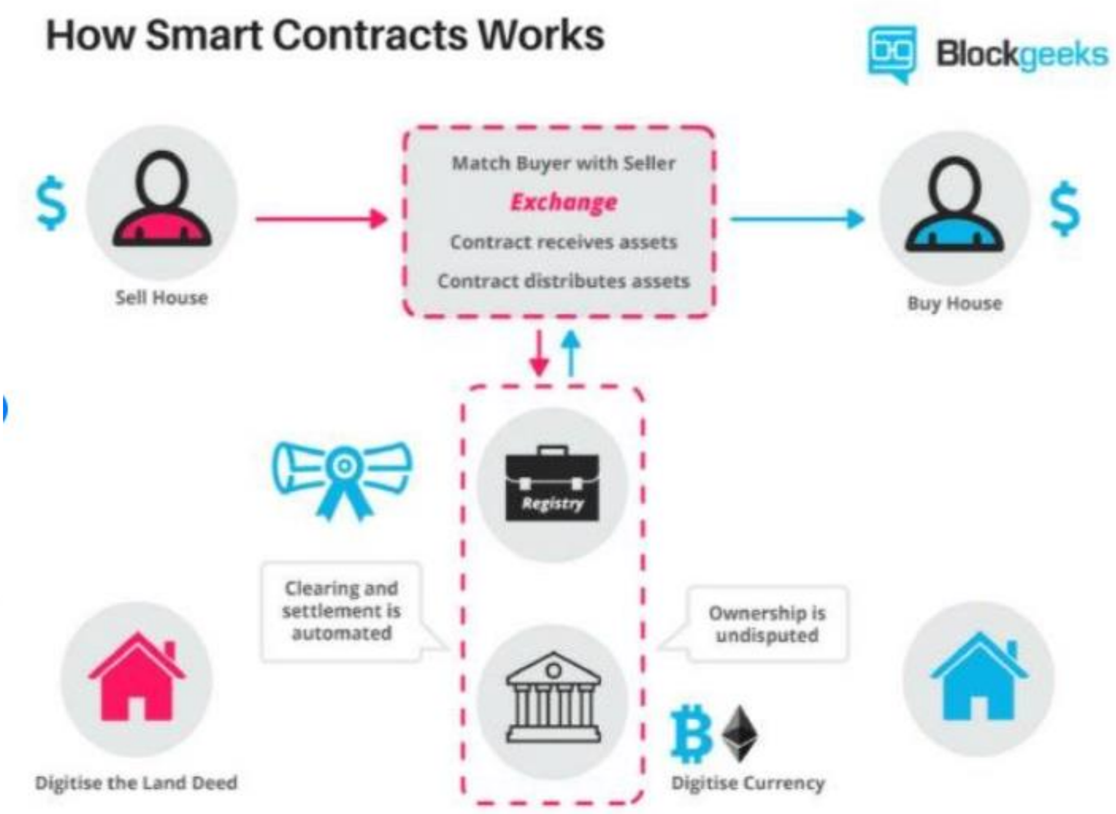

Figure 2.6 Working principle of smart contract [148].

2.1.6 Lightning Network

It has been created to solve scalability problem of BC network. The main aim is to enhance the capability of system to make it more efficient particularly for micropayments.

2.1.7 Immutability

The system is decentralized, ledgers are distributed, and blockchain ecosystem is secure, safe, immutable, incorruptible, reliable and fast. In BC systems, transaction fees are relatively low, chains are fault-tolerant, and there is minting money opportunities compared to conventional financial systems. Also, it is possible to remove one or more blocks from the chain within help of default options and filters. The transaction of token based blockchain, nonce and hash of previous block are illustrated in Figure 2.7.

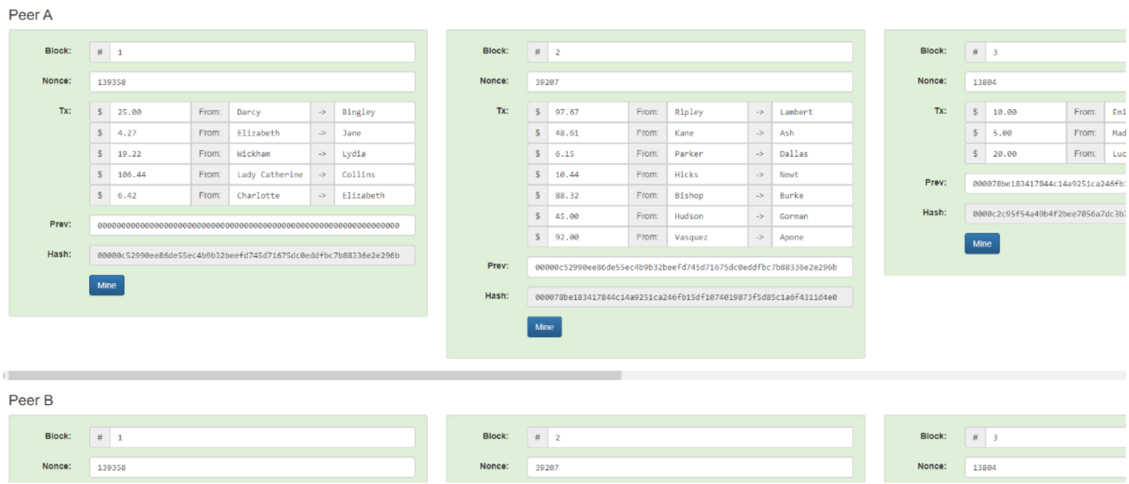

Figure 2.7 Token based blockchain, nonce, hash and transactions [149].

If someone wants to change the data on Block A. This is what happens accordingly;

1. Data changes on Block A.
2. Block A's hash changes because data is used to calculate the hash.
3. Block A becomes invalid because its hash no longer has four leading 0's.
4. Block B's hash changes because Block A's hash used to calculate Block B's hash.
5. Block B becomes invalid because its hash no longer has four leading 0's.
6. Block C's hash changes because Block A's hash used to calculate Block B's hash.
7. Block C becomes invalid because its hash no longer has four leading 0's.
8. All next block's hash value changes becauce of previous block's hash.

2.1.8 Mining

The procces of finding a solution to the blockchain problem. For example, the problem would be finding a hash that starts with 6 zeros. In general, Bitcoin uses the term mining and Ethereum uses it as validation procces. Both mechanisms are very similar to each other. Bitcoin chooses the user who solves the cryptographic puzzle first, but Etheruem chooses the random validator that regarding directly proportional to the stake of user as validator.

2.1.9 Longest Chain Rule

The blockchain system accepts only the longest chain as validated chain in the system. It makes sence because of the difficulty of manupilating the longest chain.

2.1.10 Minting

It is some kind of money producing procedure by using consensus algorithms such as PoW, proof-of-stake (PoS) etc.

2.1.11 Inflation Problem

Cryptocurrency producing is limited by using some algorithm. Therefore, it is getting harder to create new tokens. We can say Bitcoin is finite and limited to maximum 21 million Bitcoins as well. Miner reward system for successful miners get half for every 210.000 blocks. So, this reward system prevents occurrence of inflation. Major elements of the blockchain ecosystem are shared ledger, node application software for connecting the blockchain, virtual application, and consensus algorithm.

2.1.12 Types of Blockchain Structures

There are two types of blockchain ledgers: permissionless and permissioned [34]. While the ledger of a public blockchain is totally transparent and permissionless, and anybody may view it, it is open source, distributed and decentralized. Therefore, it means anyone can read, write, and audit the blockchain. The ledger of a private blockchain is only accessible to users who have been granted permission. It is mainly used for companies in terms of determining from organization who to read, write or audit the ledgers. Consequently, it is possible to construct many channels and link only some users to them; non-registered users cannot view the data, and confidential information will remain private. Consortium Blockchain means that, consensus process is fulfilled by only a few pre-selected people. Also, these preselected people can get together to make decision about the best benefit of the system. Permissioned and permissionless blockchain types are illustrated in Figure 2.8.

Further, instead of utilizing their real identities, all users in blockchain systems have public and private keys. While everyone has access to public keys, private keys are unique to each user and are used to sign transactions. Hence, the first iteration of blockchain, the Bitcoin network, is known to be pseudo-anonymous. RSA is the first invented algorithm which is used for encrypting data in a secure manner. RSA works with two different keys, the public and the private key pair. Public key is a unique string and Private Key is cryptographic algorithm that provides to encrypt and decrypt to make blockchain secure. Encryption is a process which changes the format of data from readable to unreadable and to incomprehensible. Therefore, the data gets an impossible to

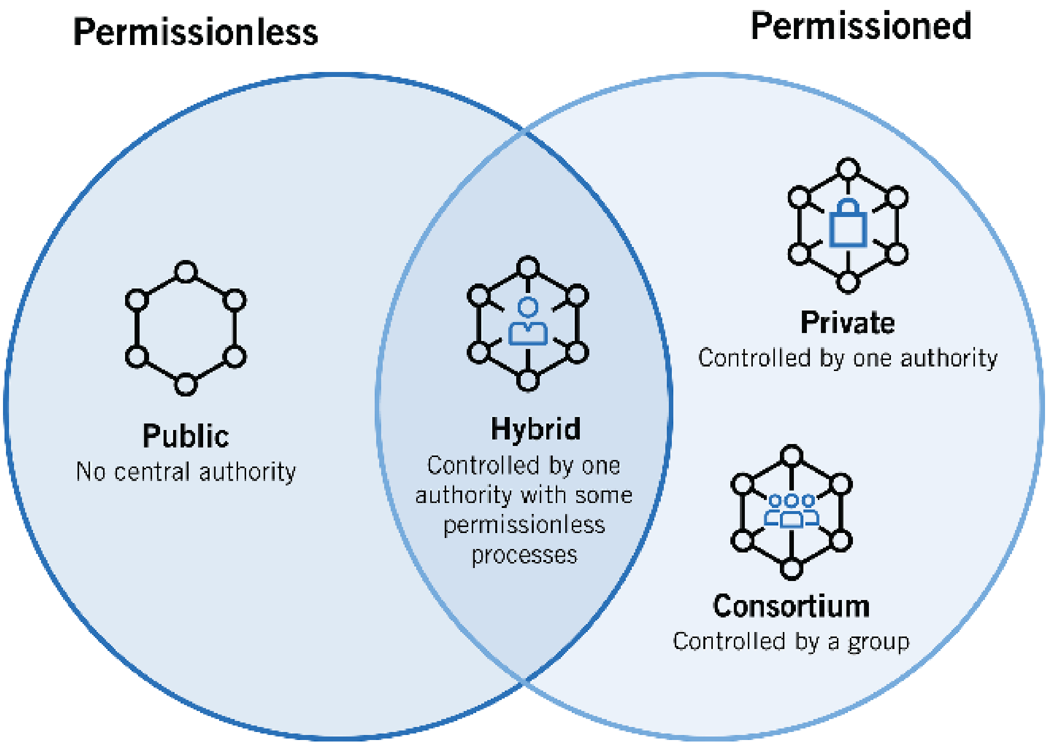

Figure 2.8 Permissioned and permissionless blockchain [150].

obtain and fully covered from possible misusage. Encryption is main part and main goal of block chain technology.

In addition to the fact that the blockchain network comprises multiple components, the importance of the users involved in the network cannot be overlooked. The system needs an incentive design to ensure the participation of system users in the network and maintain their continuity. An incentive is a component of a platform's value proposition that helps organize the system for which the platform's token will be designed. Pay-for-performance reward systems that award individuals with money are examples of incentives, as are systems that do not involve any financial rewards at all [35].

Ledger is a file, which is growing constantly, keeps records of transactions on blockchain network in a format illustrated in Figure 2.9. Three types of ledgers existing. Common type of ledgers are Centralized Network, Decentralized Network, and Distributed Network.

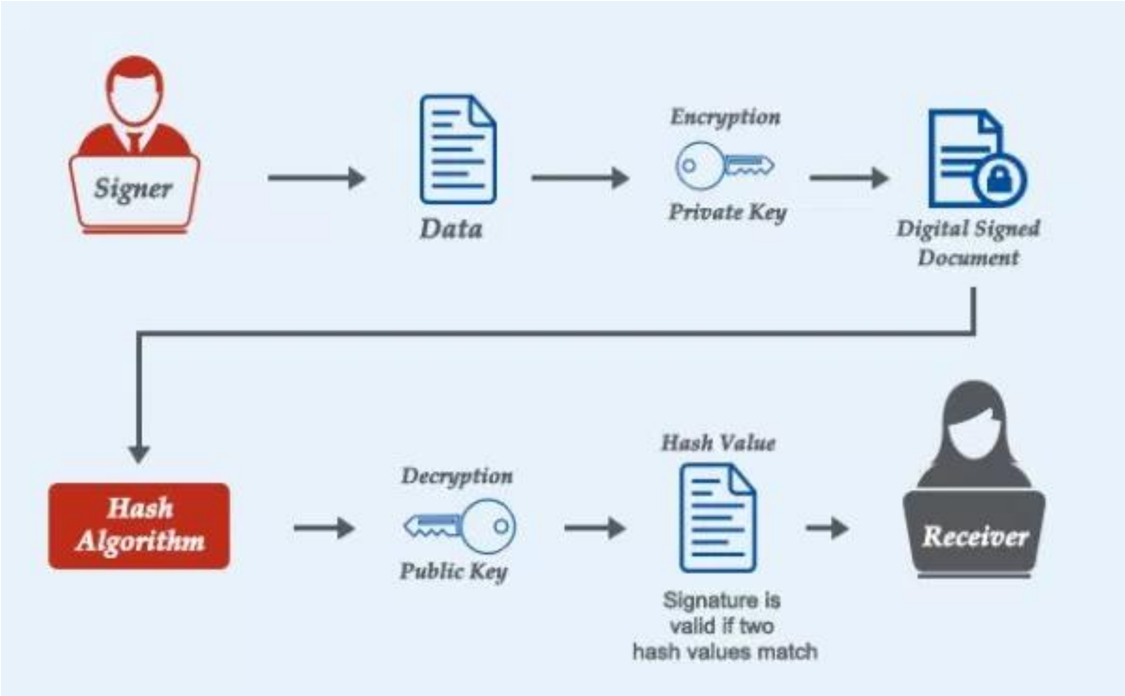

Figure 2.9 Blockchain transaction [151].

2.1.13 Benefits of Blockchain

Blockchain works in real time, therefore quicker settlement of trading is possible and aprpriate for real time energy trading operations. There is no need for third party organizer and so there will be no fee for intermediary costs except communicational costs. Secure, hack-proof and reliance, means blockchain uses very modern cryptographic algorithm not to be hacked. All types of attacks and fraud will no more permitted because of the use of distributed ledger technology. Immutability means blockchain system registers all transactions in a chronological manner. Therefore, all blocks are unalterable. Anonymity means everybody in the system knows all transactions, but nobody knows about the transaction in details, the real identity of the sender and receiver. Blockchain is a trusted approach, due to its open-source nature compatible with other approaches. It is safe, incorruptible, using cryptographic base, there is no central authority to control system, only the system itself controls and canalize the way how the blockchain works. Transactions and other operations managed by itself. Together with the immutable property of blockchain, it is significantly trustworthy.

2.1.14 Downsides of Using Blockchain

Apart from huge positive sides of using blockchain it is argued that, there has beensome downsides. For instance, being out of the common monetary system means there will be always possible illegal trading by using blockchain technology. Also inflation problem, potential double spending attack problem, expensive transaction fee for small transaction compared to ordinary banking system, 51% attack, due to the increasing data size increasing transaction costs, would be said. On the other hand, there are lack of talented technical people when we consider huge possible application area of the blockchain. Also, scalability problem means that it is limiting the blockchain network due to the size of transactions. Currently bitcoin transactions are limited to 7 transactions per seconds. Particularly in energy blockchain, the cyber-security, scalability and transaction cost seem considerabaly significant problems.

2.2 Consensus Algorithms

A consensus algorithm (CA) is a method that ensures unknown nodes to reach a consensus. Therefore, every participant of the system accepts the change of the data over the system. Consensus algorithms enable a consensus on specific requests in distributed systems. As shown in Figure 2.10, all users are connected to each other and due to create collective reconciliation they need CAs. Consequently, CAs are used to build a blockchain framework that does not require mutual trust. They play a critical role in ensuring the security and efficiency of the blockchain.

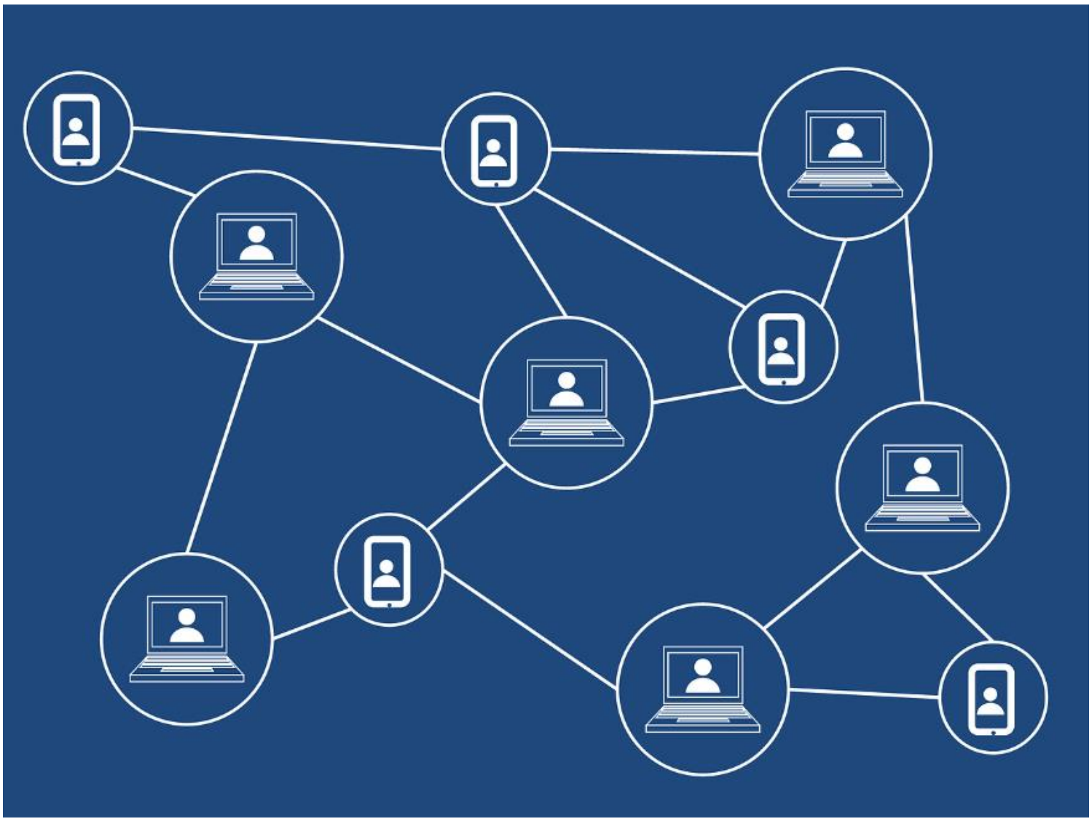

Figure 2.10 Blockchain connection diagram [152].

Choosing the best consensus algorithm for a given problem is critical to enhancing the system performance, which could lead to an increase in the number of blockchain-based applications. There are many different types of CAs. All existing CAs are grouped under two main categories: lottery-based and voting-based (Figure 2.11). Voting-based consensus techniques are democratic because they achieve consensus on critical network decisions by calculating the number of votes cast by nodes on the network. Random-selection-based CA methods are more scalable, and these lottery-based CA methods require the consolidation of multiple chains. The validator, or the node that selects which is the next block to be appended to the ledger, is elected by the lottery-based consensus algorithms. These elections are similar to those of a lottery. The winner is the validator, and a new draw is required for each new block. Voting-based methods are quicker to achieve finality but slower to reach a distributed consensus because of message exchanges between nodes. To summarize, each algorithm has its own set of benefits and drawbacks based on the system's purpose and requirements [31].

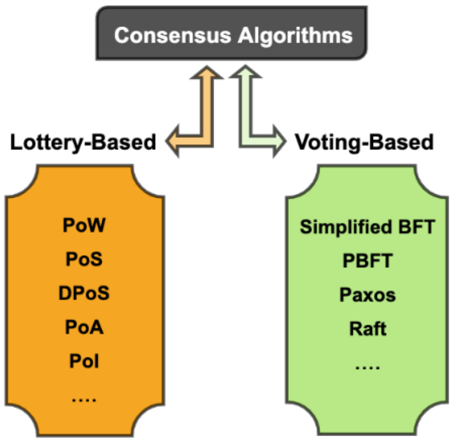

Figure 2.11 Lottery-based & voting-based consensus algorithm

In the context of EV energy interactions, there is no need for a high volume of energy or money transfers because of the lack of consumed/produced energy by EVs compared to other energy-related transactions, such as high power producing energy units' energy trade volume. In most cases, the traded energy of EVs is extremely low. Thus, the selected CAs for EV projects need to be secure, but what should be prioritized is the energy consumption feature of the CAs for EV projects. In short, the CA should be sufficiently secure to ensure all transactions but more energy efficient not to waste energy. High electricity consumption may exceed the requirements of low-value low-cost transactions for EV charging. From the DERs' perspective, security would be much more important in mitigating possible cyber-attacks because the potential high-value money transfers would increase hacker appetite. From the electricity market perspective, the security, scalability, and transaction period of the system are much more significant than the energy consumption. How does a transaction get into the blockchain is illustrated in Figure 2.12.

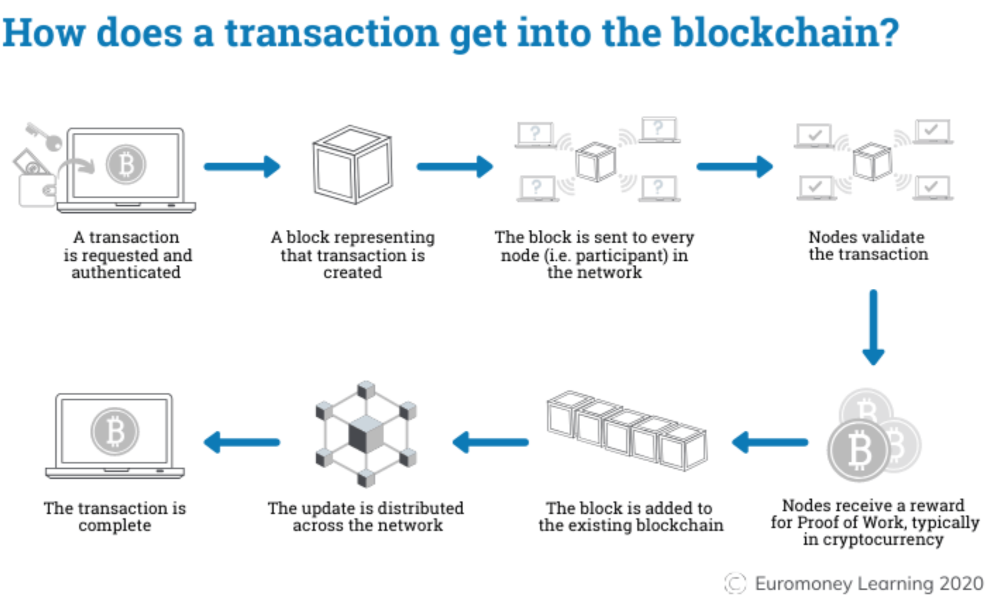

Figure 2.12 How does a transaction get into the blockchain [153].

In addition, the duration of the transaction settlement is a considerably important qualification for CAs. The transaction period represents the speed of the system, and all parties, especially the DSOs and EVs, require higher transaction speeds. Grid connection/disconnection can occur at any time from the EV's perspective. However, DSOs would somehow be in the center of the system. It is a fast event because of the electric vehicle owners' (EVOs) usage habits and reduction of charging period with the help of new quick charge technologies even for a few minutes. Therefore, transactions must be sufficiently fast to reach the flow of life [36]. Privacy is an indispensable characteristic of CAs. Data privacy is related to anonymity [21]. Nevertheless, data security concerns protecting data from unauthorized access. For EV users, a trip, either personal or business, is always considered sensitive personal data. Thus, all personal data need to be preserved in a top-level secure manner. To prevent any possible exploitation, the selected CA must provide data privacy and security assurance.

2.2.1 Several Consensus Algorithms in Energy Sector

While designing or selecting a proper CA, electric energy, computational CPU power, or the amount of money should be considered. Validation or incentives determine system vulnerability to malicious attacks or potential cyber-attacks and result in an equilibrium between system security and costs. High cost distributed consensus solutions are worhwhile to endure with the aim of creating more secure blockchain environment. However, in addition to that necessity, private blockchains can be redundant, and limited expenditure is sufficient in most cases. From the perspective of the DERs, the security of the system is a more important feature, whereas EVs require high incentives, maximized privacy, and a lower level of energy consumption. In summary, the selection criteria change from one project to another and depend on the requirements of users. From the EV perspective, the selected CA should highly incentivize users to participate and share their CFUs publicly for everyone’s benefit. In addition, high-level privacy is a significant requirement in the sector. Nevertheless, from the DERs perspective, the security of the system is more important due to possible high-volume energy transactions.

Several CAs have been investigated in the literature, but CAs in energy-related studies are extremely limited. Andoni et al. took a wide view of distributed consensus algorithms and the system architecture of blockchain technologies in the energy sector [37], providing reviews of 140 blockchain research projects and classifying them according to their activity field, the platform of implementation, and strategy of consensus. P2P (peer-to-peer), M2M (machine-to-machine), B2B (business-to-business), and trading schemes are mentioned as related use cases. According to the activity field, only 7% of the studies are related to e-mobility. From the platform perspective, which is used to adopt the system, 50% of the studies use Ethereum; the most commonly used consensus algorithms are PoW (55%) and PBFT (15%), respectively, in all energy-related blockchain studies. Some features of the abovementioned CAs used in the energy sector are highlighted in Table 2.1 to provide brief information for the readers.

2.2.1.1 Proof-of-Work (PoW)

Proof-of-Work (PoW) is a confirmation method that creates a new block at the end of the chain. These competitors (miners) compete to solve cryptographic puzzle first to get rewarded from the system. Miners spend computing energy and hardware expenses for the sake of validation reward. This process is called mining. This system is open to everyone who wants to participate it. PoW is the most mature CA ever used. Despite its

Table 2.1 Comparison of consensus algorithms in energy

Consensus Algorithm	Main Goal	Drawbacks	Decentralization Level	Determining Verifiers Based on	Energy Consumption Level	Hardware Dependency	Scalability Level	Vulnerable to Attacks	Transaction Speed	Mining
PoW [38,39]	Sybil-proof	Energy consumption, hardware dependency	High	Work	High	Yes	High	51% attack, double-spend	Slow	Yes
PoS [40]	Energy efficiency	Domination of large stakeholders	Medium	Stake	Low	No	High	51% attack, double-spend	Fast	No
DPoS [42]	More energy efficiency, organizing PoS, fair reward distribution	Centralization possibility	Medium	Vote	Low	No	High	51% attack, double-spend	Fast	No
PBFT [43-44]	Improving security level in an economical way	Low scalability, possible Sybil attack in large scale networks	High	Vote	Low	No	Low	Sybil attack	Slow	No
DAG [47]	Speed, scalability, reducing hardware dependency	Centralization possibility	High	N/A	Low	No	Low	-	Fast	No
DBFT [45,46]	Improving speed and scalability of PBFT	Centralization possibility	Medium	Vote	Low	No	Medium	51% attack, double-spend	Slow	No
PoB [41]	Alternative Agreement of PoW	Energy consumption, hardware dependency, domination of large stakeholders	High	Burnt Coins	High	No	Medium	51% attack, double-spend	Fast	Yes
PoAu [49-57]	Speed, low transaction fee, Suitable for DApps	High centralization possibility	Low	Random among trusted nodes	Low	No	High	-	Fair	No

high security and scalability, the main problem with PoW is the huge amount of energy consumption and its speed. PoW based on reputation (PoWR) is used to minimize transaction confirmation latency and new block creation time. The efficiency of energy trading, load balancing level increased, and computational complexity was minimized by leveraging contract theory in EV energy trading, but storage and scalability issues remain [38]. A credit based PoW consensus algorithm is proposed to ensure a secure and reliable smart city environment [39]. In PoW mining a block depends on the work that miner does, takes more energy than PoS, in order to attack the system more than 51% of users must act to gather.

2.2.1.2 Proof of Stake (PoS)

The other mature and proven CA is Proof-of-Stake (PoS), instead of using hash function PoS uses digital signatures. This confirmation method suggests that a set of nodes decides to validate beforehand and there is no reward system as well. Probability of adding a new block and validating it is directly related to number of tokens that participant has. In this system, miners take only small amount of money for the sake of transaction fees. It is more and more cost efficient compared to Proof of Work algorithm and one of the promising application fields is the Internet of Vehicles [40]. However, it is argued that its energy efficiency and fast structure make the rich most probably richer.

In PoW mining a block depends on the work that is done by miners, takes more energy than PoS, in order to attack the system more than 51% of users must act to gather. In PoS, probability of validating new blocks depends on directly their share of coins. PoS is more energy efficient and offers faster completion time. In order to attack the system majority of all the coins is needed. It is energy efficient because the system selects random validators to add the new block and those validators are only got rewarded.

2.2.1.3 Proof-of-Benefit (PoB)

Another CA, the PoB, has much the same idea of proving transactions like PoS and has similar issues. The mechanism with an online benefit-generating (ONPoB) algorithm has been proposed and argued to be likely to substantially reduce power fluctuations in future smart grids [41]. It has pretty much the same idea of proving transactions with PoS and, thereby, has similar issues.

2.2.1.4 Delegated Proof-of-Stake (DPoS)

DPoS is a more energy-efficient and scalable but semi-centralized version of the PoS. DPoS consensus-algorithm-based energy sharing was introduced into the internet of vehicle model to design a more efficient trading environment [42].

2.2.1.5 Practical Byzantine Fault Tolerance (PBFT)

Main aim of this consensus algorithm is to ensure the collective decision and safeguard against faults of the system. If a particular node is faulty then the methods prevent the message to reach in time and hence PBFT guarantees the safety of the blockchain. The main aim of these methods is to eliminate possible nodes, which can be fault or malicious. If we assume that the number of replications between the peers with R, (R = 3*f + 1) defines how many nodes can be faulty. Here f represents the number of maximum faulty nodes for network to work securely. It is a faster and more economical solution than PoW. Unlike PoS, there is no required asset for the consensus process; it is argued to increase transaction throughput and reduce transaction delays [43]. Another study proposed a game-theory-based PBFT consortium blockchain and considered the profit of the energy seller in the P2P trading scheme [35]. Contrary to the advantages of PBFT, its disadvantage is that delays can occur as the network waits for all nodes to vote.

2.2.1.6 Delegated Byzantine Fault Tolerance (DBFT)

Delegated Byzantine Fault Tolerance (DBFT) uses PBFT's mathematical solution with one difference—there is no need to wait for all nodes to vote. This less delay-offering solution may threaten network decentralization. A DBFT application was proposed as a secure charging scheme for EVs [45]. A utility based DBFT consensus algorithm is used, and it is argued that an optimized smart contract ensures fast and reliable mining and validation processes for EV location preservation [46].

2.2.1.7 Directed Acyclic Graph (DAG)

The directed acyclic graph (DAG) verification process is faster than PoW/PoS; additionally, power consumption is extremely low, and no mining process is needed [47]. In the study of Liu et al., proof-of-eligibility based on BFCV (Byzantine-fault-tolerance-connected vehicles) was used to make a group of vehicles within the vicinity of the information source provide a correct consensus to ensure the safety of vehicles in traffic [48].

2.2.1.8 Proof-of-Authority (PoAu)

Proof-of-Authority (PoAu) is a type of modified PoS algorithm that is seemingly more appropriate for utility companies to govern and regulate in a centralized manner [49]. V2G has some concerns such as relatively transparent information, excessive transaction quantity, unrevealed rules, and randomness of trading hours. To overcome these issues, the PoAu consensus algorithm may be chosen. It is preferred to reduce the need for computing resources, enhance the efficiency of transactions, and eliminate mining requirements. The identified aggregator nodes are privileged, and charging piles are ordinary nodes—there is no need for ordinary nodes to store all other transactions, and only the storage of the privileged node's record of all transactions is sufficient [50].

2.2.1.9 Byzantine Fault Tolerance (BFT)

Byzantine fault tolerance (BFT)-based blockchain is used and compared with PoW under finality and scalability performance, and the results support the BFT [51]. A pricing-based incentive mechanism was proposed with the help of a proof-of-reputation algorithm to efficiently reach consensus in vehicle energy delivery networks [52].

2.2.2 Blockchain Security

Blockchain offers decentralized, secure, immutable, trustworthy data management opportunity. However, the blockchain system has highly protected environment against cyber-attacks, nevertheless some kind of potentail attacks may occure to manupilate the system and some of them are mentioned hereinbelow.

Birthday Attacks: Birthday attack is a cryptographic attack in order to abuse the cryptocurrency system. The main idea is to use birthday problem in probability theory. It represents a mathematical exploitation method for cryptographic attacks. The success of this attack is highly dependent on the increased frequency of collisions found between random attack attempts and a set degree of permutations, as mentioned in the birthday paradox problem.

Double Spending Attack: It is a situation that one particular digital token is spent multiple times by copying digital coin files. From the point of cash money spending, it is impossible to spend one particular coin two times. But in term of cryptocurrency, it is within the bounds of possibility. Hence it is possible to copy and rebroadcast the transaction on the network after validation of the first transaction. Blockchain network's main prevention way for double spending is to implement a confirmation mechanism from multiple parties before the actual transaction recorded to ledger. Mining and PoW procedures (consensus algorithms) make transactions computationally impractical to modify. Double spending problem solved by Bitcoin by using chronologically ordered records on the pool (mempool) of transactions. If some holder plans to spend one currency multiple time, miners can understand and validate only which transaction has the higher number of confirmations. Therefore, others will not be validated as well.

51% Attack: It means, when a group of miners, whom have 51% participants of the whole network and its computational power, can manage the blockchain structure to dominate transactions and spend coins twice. Attackers can halt transaction validation process by using this method, or they can generate blocks faster than all others. However, it is highly impossible to occur although it is theoretically possible.

Chapter 3

Grid Stakeholders and Blockchain

DSOs have new roles and responsibilities in the decentralized energy era. From voltage control and management of power flow to the contribution of nationwide frequency control, the new crucial operation and working areas of the DSO need considerable precision and sensitivity. The increase in the number of distributed energy resources (DERs), electric vehicles (EVs), and the increase in the need for a new energy market has led to new requirements for systems like blockchain to create a decentralized, reliable, and secure energy environment. Blockchain with EVs, energy storage systems (ESSs), DERs, and energy markets were investigated from the DSO perspective.

3.1 Use of Essential DSO Services and Blockchain

Supervisory control and data acquisition (SCADA) and Advanced Metering Infrastructure (AMI) offer convenience remote controlling opportunity for DSOs to handle grid and costumer management tasks more efficient and in a timely manner.

3.1.1 SCADA

SCADA is one of the key instruments for grid management of DSOs to monitor and orient grid events and power flow, manage active/reactive power, and detect electrical fault points. The reality of the presence of cyberattacks creates a considerable need for intensive attention to the SCADA system for reasons of security, privacy, reliability, sustainability, and continuity of electricity procurement. SCADA systems typically comprise elements such as sensors, relay devices, circuit breakers, voltage regulators, power measurement units, and communication network components [53]. It collects all distributed information of sources and data in a central database, and all these system parts lack computational abilities because of low computational power. The absence of computational power on controlling units such as sensors, circuit breakers, actuators, delays, or rarity of computational power on other SCADA units causes failure to participate directly in BC as a node. In addition, the current SCADA and grid management systems' impulse response must be within seconds in BC systems.

Conversely, BC technologies consume more time than the existing structures. Kong et al. studied countermeasures to improve this time efficiency by facilitating a multi-chain approach and using the PBFT consensus algorithm [37]. A novel consensus algorithm—PoRCH (Proof of Random Count in Hashes)—which does not require any incentive or penalty mechanism for validator/miner nodes, has been proposed [54]. The security and robustness of the entire power grid mainly depend on the security of the SCADA system because the grid's centralized nature and structure are vulnerable to cyber-attacks [11-55]. The high-level decentralized SCADA system architecture is highlighted to protect the grid from data poisoning and identity spoofing [56]. Except for the difficulty of managing centralized systems like SCADA as decentralized systems like BC, the abovementioned grid devices are indispensable because of their physical connection structure, the natural structure of electricity, and lack of an alternative to these devices. However, the SCADA system pieces are under the control of DSOs, and the weak points of all systems are not tamperproof against physical interventions as well. This point needs to be investigated in detail.

3.1.2 Advanced Metering Infrastructure (AMI)

In general, AMIs are high-level measurement, metering, and monitoring devices that allow widespread communication among all grid users. In particular, smart meters and telemetry devices are assumed to be sealed tamper-proof devices to confirm the amount and flow direction of energy [57-58]. According to their adoption by the current TSO/DSO to the smart grid, the environment requires digitalization and advanced capability to monitor the grid's power flow, voltage, frequency, and stability. Teufel et al. discussed the current and prospective applicability of BC technologies in the energy sector [20] from old to new energy transformation processes characterized by structural coupling with multiple sectors and technological developments. In this context, as well as the current importance of smart meters, most will probably play a key role in this transition. The smart meters and BC of DSOs ensure the trust and security of the system, and that DSOs manage to bill and trace energy exchanges [59-60]. These trusted parties, considered BC nodes, provide connections between users and the outside world. As one of the main components of the SG is smart meters, this type of current technology must be utilized to adapt blockchain to the new energy trading era [61-62].

Despite the immutability, transparency, resilience, and automation advantages of BC, little is known about the influence of current hardware and communication limitations [63-64]. The authors demonstrate a real case study of BC-managed microgrids that offer a higher bandwidth to maximize the throughput per second in an AMI environment. In addition, the number of validators, the maximum data rate of the communication infrastructure, and the available network infrastructure directly affect the throughput and latency. Additionally, the hardware capacity of smart meters is adequate nearly nowhere and requires additional improvements. Thus, governments or utility companies should further push smart meter producers to reach the level of the novel, sophisticated, and customizable devices. Enabling highly efficient collaboration between local prosumers, consumers, and DSOs is viable if and only if there are computationally capable smart meters.

However, smart meters can send and receive data about consumed or produced energy and additional information such as price and cut off data for managing and billing [65-66]. Smart meters have many security vulnerabilities, such as the interference of unauthorized users through manipulations at a physical metering box and of metering data and interventions of eavesdroppers in wireless/wired communication channels to capture customer data for malicious purposes [67-68]. Automatic billing services for all electricity users may reduce the overall administrative costs of DSOs, which may secondarily reduce the electricity prices for customers as well [6]. BC has a remarkable cyber security ability to protect all users and promises considerable benefit to society. However, physical interventions and manipulations must be prevented by DSOs. Instant physical attacks and retroactive past attacks and measures to prevent such situations should be considered in light of the immutability of BC technology. Another important point is how the DSOs should interpret past attacks and how to penetrate BC to correct all wrongdoings. Under these conditions, the responsibility of DSOs is as significant as the general security of the entire energy environment. This DSO role, its limits and its scope on the system are regrettably mentioned nearly nowhere in the BC and energy-related studies. Although the adaptation of current metering, measuring, controlling, and communication systems are real requirements, BC systems require high throughput and speed. However, the current abilities and hardware backgrounds of smart meters are limited.

3.2 Electric Vehicles & Energy Storage Systems

The growing popularity of electric vehicles (EVs) has led to new challenges and opportunities in the modern world. From the electric car customers' perspective, they offer a lower carbon footprint and environmentally friendly choices to individuals, cheaper journey opportunities, and perhaps more car engine power for low-income customers who are eager for higher power. From a car maker's perspective, they provide opportunities to make electric cars more suitable, efficient, and sufficient, and thereby gain market share. However, the main reason for forcing electric car makers to move toward this area and EV users to refer to this choice is the government's law enforcements to reach lower CO_2 emission levels. The CO_2 emission standards of the European Union will gradually force car manufacturers to reach an average EV sales share of 5% in 2020, 10% in 2021, and 20% in 2025 [69-70]. From the distribution system operators' (DSO) viewpoint, EVs provide new opportunities for creating more sustainable energy systems and smoothing consumption patterns, thereby entailing less distribution grid investment and fewer technical losses. Contrary to these positive effects, there are certain adverse effects of EVs.

The more decentralized electricity grid participants such as DERs (solar, wind, hydro) and EVs there are attached to the grid, the more powerful, reliable, and robust a distribution grid that can come into existence. Contrary to that, the instant production and consumption patterns can cause electricity disasters, even nationwide power outages. The proposed blockchain and EV design should ensure grid robustness by attending DSOs, perhaps by including the DSO as part of the incentive mechanism. In the aforementioned system framework, DSOs can decide the congestion points with deficient or surplus energy data beforehand to canalize EVOs to those specific locations. If the grid needs more energy, then fully charged vehicles are directed to energy shortage points through an incentive mechanism and vice versa. Thus, EV and blockchain interactions ensure the sustainability of the national grid. However, the cost of producing and delivering electricity is not truly dependent on the amount of energy used but mostly depends on that of short-term demand. As grid investment is directly related to the peak load of the network, intelligent and self-sufficient grid management schemes are required. In particular, EVs can lead to more distribution grid investment because of the possible instant load increases if they cannot be managed effectively. To mitigate the investment amount of DSOs, many countries have created different political demand-side management (DSM) aspects. In addition to these grid enhancement offerings, EVs/CFUs can work for grid capacity improvement; if the EVs are canalized to the energy shortage points, then the short-term grid investment expenses would decrease. Finally, centralized and unidirectional power flow can cause more power loss owing to the extremely long transmission and distribution networks. A decentralized grid with an increasing number of EVs makes for a more energy-efficient system because of the proximity of the consumer and producer to each other.

From the viewpoint of EV makers, modern electric cars have attracted eco-sensitive customers by using environmentally friendly solutions, such as suggesting emission-free EVs. Despite its benefits in creating new trading opportunities by utilizing EV technology, EV producers will put up with the need for more research and development investment expenses. However, it is considered compensable because of the ever-growing number of EVs sold. Additionally, multi-dimensional problems of EVs are expected to be solved in many ways in the future. However, expanding the usage of EVs worldwide with the help of blockchain makes them beneficial for all customers and most probably encourages EV producers to make vehicles better, cheaper, and beneficial to users. In sum, an increase in new EV sales and more customers choosing EVs would be likely to heat up the car production sector, which would be beneficial for car producers, potential customers, DSOs, and the environment.

In addition to these impacts on all parties in general and EVOs in particular, one specific issue can be stated as the main problem, the range of the cars from the single charge and, consequently, the availability of charging utilities/stations. Despite EVs being cheaper, more environmentally friendly, and relatively comfortable, their battery performance drastically limits their range. Although car producers are working on more durable vehicle power supply solutions, it is a challenging problem to solve in the near future. However, alternative solutions can be created by third parties. The problems of EV ranges and the locations of charging facility units can be solved by using the distributed, private, and secure structures of blockchain networks. Imagine traveling from one location to another by EV, where most of the time, the EVO is obligated to navigate to reach the target area in an optimum manner. In this journey, the fastest and cheapest route will certainly be chosen. However, finding possible locations of service areas and alternative charging opportunities is another major obligation for travelers not to be stranded on the road. Thus, convenient charging facility units that belong to other EVOs become a part of the solution to the already diminishing battery power of the EV. If all included CFU owners make their devices available for strangers when they are not used, EVOs can spend less energy and time to find charging locations. Therefore, concerns regarding reaching CFUs before depleting the battery will be reduced. Finding appropriate CFUs for blockchain-user EVOs will be considerably easy in city centers and even in rural areas, because of the distributed available CFUs. The main obstacles to the spread and proliferation of CFUs and a charging system are privacy, security, and lack of encouragement processes. Hence, in the BC-centered EV era, EVOs will be free to travel far distances and feel secure and safe and their privacy preserved. Nevertheless, CFU owners will be free to trade (sell/buy) energy with other participants without third-party intermediaries. Additionally, through the automatic payment mechanism, both the grid and off-grid electricity stakeholders can participate in the EV charging system without having to worry about billing staff and payment details.

Apart from these positive and negative effects of EVs with BC, the owner of the grid assets, the DSO, is mentioned almost nowhere. The electricity grid is like a living being that requires regular maintenance and repair. Several grid situations, such as overloading of grid equipment, may adversely affect EV/ESS users. To keep the electricity grid alive, the DSO must manage the load and power flow directly. Rapid increases in the number of EVs/ESSs will most probably create congestion at the weak points of the grid. Hence, the overloaded charging scheme may be interrupted by the DSO using the BC structure to keep the grid alive. However, it is necessary to determine how the DSO act that situation. In addition, interruptions must be fair and sustainable for all users. This poses an obstacle to the operation of the entirely liberal and self-sufficient blockchain in energy studies.

3.2.1 EVs & Blockchain-Related Works

EVs and the e-mobility area have attracted companies and researchers because of their inevitable decentralization process. Most EV owners have a car charging facility/unit for their own use, which can be either connected to the grid (on-grid) or not (off-grid). Regardless of whether they are on-grid or off-grid electricity users, property owners or EV charging facility owners are free to rent their charging capacity and share their facility publicly when they are not using them. Thus, both parties eliminate intermediaries and allow individual trading opportunities and are also freed from commercial charging station companies' monopolies. Although this projection gives freedom to the charging station owners, it has some drawbacks, such as how to pay for the consumed energy. Might the cash system violate car owners' privacy rights? By constructing blockchain-based networks, EV owners can gain greater privacy when traveling between different locations, including even foreign countries. In this regard, Teufel et al. take a holistic approach to blockchain technology in the energy sector based on a literature review and expert interviews [20]. It considers that the greatest impact of blockchain will occur in the short term on EV integration, while in the long term, blockchain will affect P2P energy trading on microgrids. It has been argued that the most challenging part of blockchain development in the electricity sector is inflexible regulations. In addition, researchers have emphasized the need for a consensus between past and future decentralized energy systems, where blockchain is perfectly suited to this requirement. However, this study investigates all energy sectors in general and EVs in particular, apart from DSOs' interaction with others and short-term necessities of BC. Conversely, another study classified 140 blockchain research projects according to the activity field and only 7% of the studies are related to e-mobility [71].

The adoption of EVs to improve transportation opportunities requires further research. In particular, the optimum charging station location, battery limitation, management of charging scheme, and impact of the EV on the power grid require more studies [72-74]. On the one hand, EV owners expect their cars to be charged in the fastest and cheapest way. On the other hand, DSOs struggle to manage peak load and system robustness issues. In addition to these problems, one of the major problems is the privacy of EV owners and the security of the entire system. Lazaroiu et al. proposed a method based on fuzzy logic to charge fast and efficiently by connecting publicly available private charging points, and the PoS consensus algorithm is used because of its energy-saving fast structure [75]. They focused mainly on grid congestion management and peak load hour compensation. Fuzzy logic is used to generate the weight of each member of the system to generate a new block. This study focuses on the excessive power production of PV panels and stores surplus energy to reach common fairness between individuals. However, the author's major consideration is the lack of efforts to promote the involvement of EVOs/CFU owners and DSOs. EVs and energy storage units act as charging points for filling energy valleys and feeding back into the power network to reduce the peak demand that is a major DSO burden [76]. A secure and credit-based BC payment mechanism enabled V2G energy delivery in microgrids and overcame confirmation delays. The auction mechanism and a smart-contract-based trading platform on a private Ethereum network were proposed and simulated. Further, an existing metering staff of utilities remained unchanged to avoid major changes in infrastructure [77]. DSOs are argued to be incentivized by the energy transaction corresponding fee payment of the blockchain users. However, the stimulation is superficial because of the reality that DSOs prepare billing for all energy transactions, except for limited off-grid connections in some cases. Thus, the incentivizing ability of the proposed system was meaningless. Charging location selection is presented based on a protocol for dynamic tariff decisions, different pricing of energy providers, and distance to the EV. The bidding mechanism offered as an EV signals the demand, and the charging station sends bids like an auction using blockchain [78]. The price will be the lowest for EVs and the highest for charging stations. The main motivation is finding the cheapest and most appropriate CFU, but reasons for the EVOs to participate in this system are lacking. Although DSOs should be significant and natural users of blockchain/energy studies, they were not mentioned.

Despite all the abovementioned studies, reasons to encourage all EVOs, CFU owners, and DSOs to participate in the blockchain have been neglected. Fu et al. offer a cooperation system that connects companies and their customers via smart contracts [79]. For the benefit of EV users and new energy companies, a novel convenient charging system is proposed to maintain the fairness of user allocation and balance the profit of the company alliance based on a consortium blockchain. The Limited Neighborhood Search with Memory (LNSM) algorithm is used to make a faster smart contract with better performance. However, despite all these allocation schemes for the appropriate EV charging pile, the situation of the DSOs and the responsibility due to possible grid congestion resultant status were not mentioned.

Sharma et al. and Pustišek et al. focused on selecting the most convenient EV charging station autonomously, booking charging slots from remote locations to schedule charging time and cost values by implementing a blockchain-enabled EV charging infrastructure approach [80-81]. Information regarding when and where users charge their vehicles is ensured by the blockchain network. However, charging costs are detailed as the time of use, type of charging power source, and waiting time of users among others, while the DSO rights and reasons for forcing it to involve its entire system are not mentioned. In smart grid systems, P2P energy trading (ET) schemes based on Ethereum smart contracts to procure more secure, private, and adequate latency and real-time settlement have been proposed [82]. It is claimed that the aforementioned system design of energy trading between EV owners and prosumers, who are interested in selling surplus energy, is facilitated. The performance was evaluated by comparing the data storage cost and latency, but scalability was not verified. Nevertheless, DSOs and measures to softly force the EV/CFU owners to enter the system are not touched on.

When all the abovementioned blockchain and EV-based studies are examined, they investigate the energy costs of EVs, fast and efficient charging, selection of appropriate CFUs location, scheduling, and booking charging slots automatically. Although they are trying to solve the main problems of the state-of-the-art confusions of EVs, there is a lack of linkage between DSOs' interaction with EVs and a shortage of encouragement of EVs/CFU owners to participate. Although Blockchain offers decentralized networks, owing to the reality of the existing grid structure, the central management of DSOs plays a significant, non-negligible role. In summary, there is a considerable requirement for a scheme that offers less grid capacity enhancement investments, fewer grid losses, and a sustainable power system but strengthens DSO operations through the blockchain's decentralized structure as well. However, struggling to find appropriate CFUs should be facilitated by a reward mechanism for EVOs and CFU owners so that the traveling area of the EVOs can be expanded widely. It is necessary to determine how to enroll DSOs and secure the rights/responsibilities of DSO while maximizing the benefit to EVs/ESSs owners.

3.2.2 Future EV Usage and Its Problems

It is not too far-fetched to expect to see EVs throughout the world in every city or rural area. Nevertheless, it is difficult to create available charging units for cars to prevent them from running out of energy. In this context, for the abovementioned reasons, most EVOs would have their own EV charging units. However, establishing a new charging facility unit (CFU) may be expensive, and the time to amortize this new device would be long. In addition, energy storage units will shortly be considerably common. These types of extra loads create an intensive need for demand-side management solutions and difficult situations from a grid management perspective. In addition, in a charging scheme, the relation between EVOs, CFOs, and charging stations requires clearer explanations. Payment details, the privacy of EVOs, and the security of the offered solutions are commonly discussed. Gabay et al. mainly focus on the privacy issue of the charging period scheduling of EVs [83]. The main issues are that car users' daily or hourly locations must be protected as private data. In summary, the main problems that will be faced in the near future caused by commonly used EVs can be described as follows:

- Finding an available charging facility during a trip is a difficult task, even impossible, in rural areas.

- Shorter and less comfortable journeys are less preferable for EV usage. Therefore, the global CO_2 emissions goal may be unattainable.
- Overloaded grid problem may make congestion management extremely difficult, even unmanageable.
- Increments in short-term energy demand would increase grid investments due to the relationship between instant electricity demand and grid capacity.
- Increments in energy demand and the number of unbalanced loads are more likely to increase grid losses and energy wastage.
- The applicability of BC technologies to the existing DSO structure is a complicated task because of the need for the central authority as the main actor.
- Constructing an EV charging facility for the EVOs' own purpose of use would be expensive.
- Privacy concerns of the EVOs' trip data are emerging.
- Security concerns and vulnerability against cyberattacks are also vital and up-to-date topics.
- Mature incentives or reward mechanisms to promote EVOs and CFUOs to participate as actors in the system are lacking.

3.2.3 Benefits of EV with the Help of Blockchain

The aforementioned negative sides of EVs can be made into positives. The benefits of the wide usage of EVs with the help of blockchain technology are as follows:

- Every EV owner can be a charging station owner; thus, a more decentralized EV network system can be created, and finding the CFUs will be easier.
- Increments in using EVs cause less global CO_2 emissions and lower carbon footprint (decarbonization) for individuals and companies.
- A reliable and robust energy system can be obtained by promoting EV usage by Blockchain.
- Decentralized bi-directional V2G and V2V low-cost energy transaction.
- Sustainable and renewable energy usage will be encouraged by providing trading opportunities.
- Decreasing technical losses of the electricity distribution grid and enhancing grid efficiency.

- Supporting EVs as ancillary services (real-time energy management) and as grid inertia sources.
- V2G and more smooth consumption pattern, and therefore, less distribution grid investment.
- No need for extra billing staff or individuals to trade face to face.
- More secure and private transactions and freedom of traveling are ensured.

The benefits of the blockchain mechanism contemplated in the study of Liu et al. are obvious: the contribution of EV charging on the smart grid improves resilience and minimizes the power fluctuation level [84]. This study aims to reduce the overall charging cost for EV users using the proposed novel adaptive blockchain-based electric vehicle participation (AdBEV) scheme. Crasta et al. proposed a blockchain-based solution to DSO to be freed from the extra burdens of the EV charging schedule and facility constraint problems while ensuring fairness between EVs [85]. Matsuda and Taraka showed that EV agent systems within blockchain platforms are adequate to maximize the value of local renewable energy sources [86]. Some benefits of the study are that the load variance of the power grid is mitigated by the effect of peak load shifting, reducing the stability and safety issues of the power grid [87]. As per the above, all general negative effects of EVs may be converted into positive ones by leveraging blockchain technology as well. However, all beneficial features of the BC seem obviously utilizable, but how DSOs will act as BC users remains unclear. Instant overloaded grid equipment and its management using a BC should be investigated. How the power flow can be oriented while saving the fairness of users is a notable issue.

Abovementioned issues and potential problems demonstrate possible adverse even devastating effects of proliferation of EVs on the grid. All these possible detrimental impacts and other issues (privacy, security) are solvable by adapting BC technology in to that area. To summarize, existence of DSO may keep EV users in suspense owing to its central nature, despite BC's improved data security feature. Also, on the other hand, EVs' inattentive consumption patterns may keep DSOs in suspense owing to relatively unexpected rise and new extra grid load of EVs. DSOs' essential responsibilities and EVs' expectations should be dealt with in common ground by utilizing wide range of BC features. Interaction between EVs and DSOs most likely gain importance, and that mutual effect will give direction to the development ultimately.

3.3 Use of Blockchain in Distributed Energy Resources (DERs) and Microgrids

The cost of renewables, energy storage, and other technological developments are rapidly decreasing; thus, this situation will prompt the users to become involved more actively in the grid. The cost of the transition from conventional grid systems to smart grid systems, with the help of AI and BC technologies, is relatively high. Nevertheless, the benefits are abundant, particularly for DER [88]. Some benefits of information technologies are said to be the lively collection of energy consumption/production statistics, enhanced grid efficiency, peak demand adjustment, and sustainable energy trading that can ensure the possibility of choosing low carbon energy sources. This provides extended support for other plug-in energy infrastructures (e.g., city surveillance systems, public lighting), advances the support of EVs, and reduces suspicions of reliability and stability concerns. In addition, effective monitoring of the grid could help address the issues of grid congestion and massive energy transfers. The resilience of the grid can be ensured against extreme weather events, acute accidents, asset failures, and even operational human errors by distributed smart devices and BC. All system components are cordially related to each other. In the modern world, uncertainties in RESs due to instant changes in weather conditions and changes in human consumption behavior may adversely affect the performance of planned P2P trading [89]. Therefore, utilities have no choice other than fight-and-innovate strategies, while acknowledging customers as potential generators through such devices as rooftop PV units [71]. However, within the grid modernization concept, the cost of system-wide participation of DERs is as important as integrating them effectively as an inseparable part of the network [90]. There is a considerable need for a novel BC structure, as DSOs influence the power grid the most and will plan the blockchain framework in the presence of DERs [8]. Nevertheless, microgrids comprise DERs and consumption units most of the time, and they are expressed as interconnected electricity devices, local balancing of electricity consumption and production, and small-scale, self-controlled grid systems [91]. However, as a highly scalable and flexible solution, microgrids are also a potential source of inefficiencies and vulnerabilities, especially because of the transmission of energy over long distances through transmission lines. The DSO is responsible for monitoring and controlling the utility network to guarantee quality and sustainability, even in a highly decentralized microgrid-based environment. Although widespread microgrid implementation collectively provides new opportunities, it also mandates that the power distribution network adapt to a new feasibility paradigm [92]. Most grid-connected microgrids belong to facility owners [93]; recognizing the contribution of microgrids to existing distribution infrastructure is a special topic. P2P energy trading projects mainly focus on microgrid-level investigations because of the existence of adaptable local markets and available information and communication technology) [94-95]. In the P2P, prosumer to the grid, prosumer to community scheme, P2P trading is probably the structure furthest from today's central grid model. Different consensus algorithms have been proposed to achieve fairness and the optimum profit of both microgrids and miners in the IoT [27]. This decentralized structure requires a decentralized solution, such as blockchain. Nevertheless, the main obstacle to P2P energy trading in microgrids is regulatory challenges [96].

The existence of DERs and prosumers creates a bidirectional power flow reality. Thus, DSOs must behave like traditional TSOs and be more active in redirecting energy. Reduction in the investment costs of DERs and widespread BC applications may accelerate the transformation process. In the future, BC technology will most likely play a significant role in the DER-connected grid with the help of its secure, distributed, and adequate structure for energy trading. However, in the short term, DSOs will remain the main actors of the grid and significant energy providers in the trading system. Production instability due to sudden weather changes may cause extreme surplus energy. DSOs are responsible for managing local and broad energy disturbances with canalizing power from more to fewer points with the help of BC under these conditions. In addition, legislation in favor of grid users will likely foster blockchain usage in microgrids. However, inner energy trading operations are relatively independent of DSOs, and the interconnection of multiple multiple microgrids scheme schemes would only be possible with the existence of a physical connection of DSOs.

3.4 Blockchain in a Decentralized Energy Market

Most studies of energy trading and blockchain have focused on the electricity market, P2P energy trading, and V2G and V2V approaches [97-99]. However, today's widespread market structure is centralized in day-ahead and intraday markets. In this energy trading scheme, transactions must be timely because of the timely usage of electricity. Contrary to classic cryptocurrency algorithms, especially in the electricity market, the transactions have time constraints on aggregation and processing. Therefore, in sufficiently large environments, communication problems and possible solutions must be strictly considered. The energy internet requires real-time settlement, intelligent interaction and decision-making, and extensive interconnection among all parties [100]. Moreover, electricity trading is distinguished from other commodities by its physical laws and technical constraints [91]. DSOs must be considered third-party validators for energy exchange not to violate technical network constraints, a methodology based on sensitivity analysis, and economic benefits [101]. Apart from maintaining the existing retail market, allowing DSOs to manage local flexibility markets and negotiate in it is an alternative solution to cope with grid constraints [102]. A possible limitation of the DSO-managed local market design is that it may fail to exceed the minimums voltage and power flow limits of the transformer [103]. To cope with these issues, the requirement for coordination efforts between users and DSOs have increased owing to the intermittency and bidirectional energy flow [63].

Guerrero et al. presented P2P energy trading in a low-voltage network with a low requirement for the DSO scenario [104]. Trading in the market occurs between closest agents. Therefore, it is argued that the mechanism reduces technical power losses and network congestion with the lowest level of DSO involvement. The main goal of the DSO is to match the electrical distance between peers. In Lee et al.'s study, messaging was authenticated for prosumers and consumers to notify and verify the injection of surplus energy to the grid [14]. DSOs' responsibilities are described as handling financial operations, monthly billing of customers and prosumers, and also maintaining the physical part of the grid, such as registering new smart meters to the system [105]. How token-based smart contracts were utilized, and the total amount of energy compared by DSO in trading [106]. Despite DSOs' responsibility to institute reliable measures to prevent customers from stealing electric power, the need for new devices or new approaches is neglected in this study. In addition, the DSO should be a guarantor for the rights and duties of each party. The transaction rate within a market time step is not discussed in this study. Owing to the distributed nature of marketing operations and its direct relevance to money, it is highly applicable to BC, despite some drawbacks such as lack of regulatory legislation, deficiency of distributed hardware capacity, and the significant lack of practical experiments. Near future energy market structure towards a decentralized BC-based general market is illustrated in Figure 3.1.

The primitive version of the market contained only a few market participants (TSO, DSO, and big power plants). Power flow was unidirectional, and trading was somewhat limited and dependent mainly on TSO operations. The TSO was the central authority responsible for electrical and commercial affairs. The main structure of the present national market comprises several users i.e., DERs, prosumers, big consumers, and microgrids. Consequently, power flow has started becoming bilateral, and the market is freer than before. Although the DSO has new roles (DSM) on the grid, with the TSO overwhelmingly managing the main tasks (frequency control, ancillary services), the

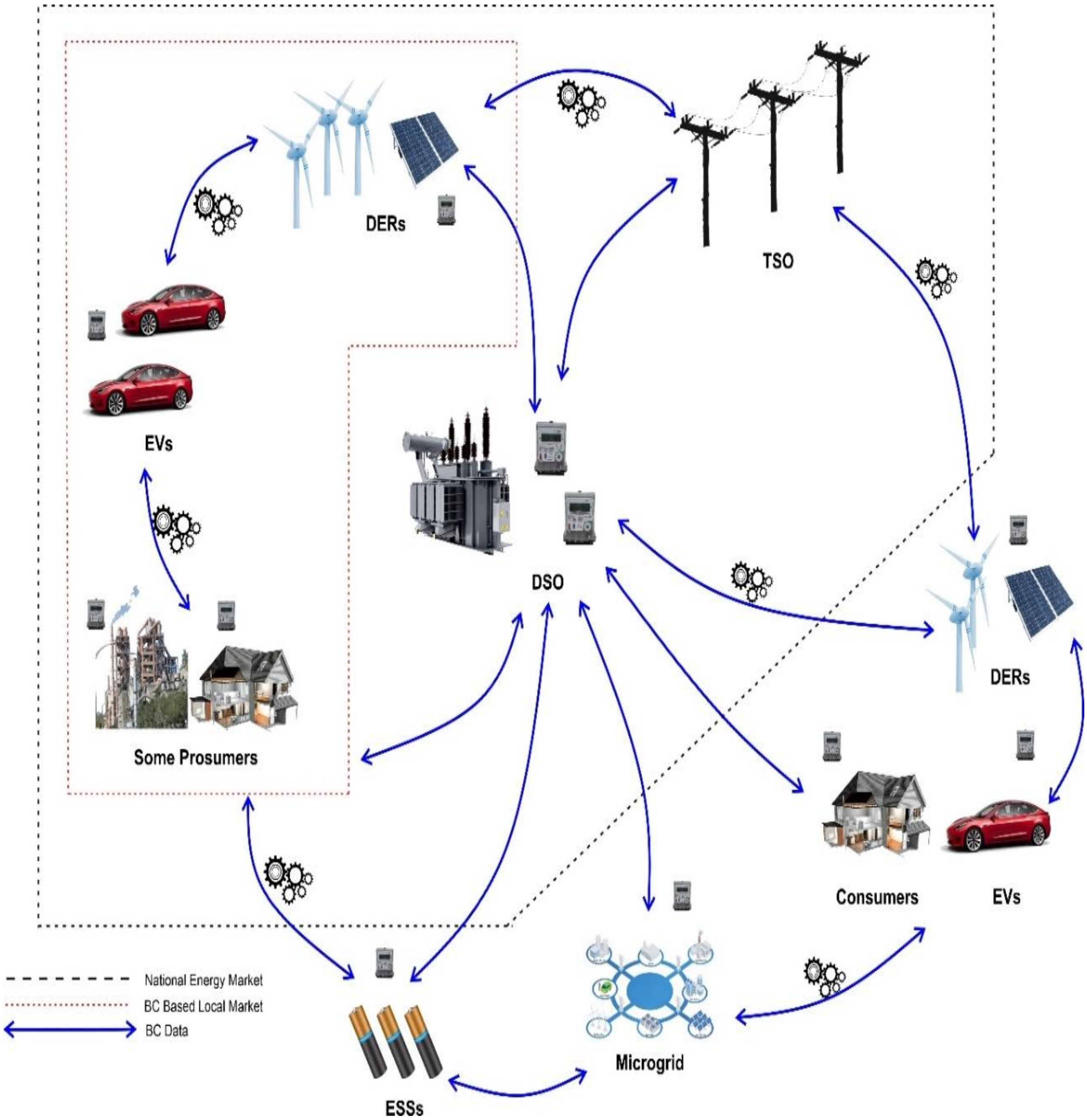

Figure 3.1 Near future energy market structure towards a decentralized BC-based general market.

DSO renders support to the TSO. However, the inclusiveness of the market is satisfying, and most small consumers are still out of market. In addition, the BC-based national market is far from being true. Contrary to that slower development, in the near future the inclusiveness of the national market is expected to be wider, and most users will be market participants. More importantly, an increase in the requirements of DSM, the number of rooftop PVs, new distributed electricity generation methods, and particularly EVs may take DSO a step forward. Additionally, the development of BC and brand-new EVs will most likely stimulate the transformation process the most. The proliferation of BC and new pilot projects based on BC may create new interconnected local markets also connected to the national market (Fig. 2). These local markets will most probably comprise EVs, DERs, and DSO in the first place. However, in the new era of BC, the market may not embrace all small electricity users, and the DSO will continue to perform its critical duties. The DSO's electrical and commercial active role may effect new issues such as centralization, manipulation, and intervention possibilities in the new market model. To arrive at the ultimate decentralized BC-based energy market target, the limits of the DSO, technical responsibilities, and commercial duties must be strictly determined.

3.5 Blockchain Application in Other DSO Aspects

3.5.1 Blockchain Contribution in Demand Response

Blockchain's incentive mechanism and smart contract's transparency and reliability features will have a positive effect on the smart grid. Power grid quality criteria can be ensured by the DSO with the aid of regulating the voltage/frequency fluctuations. The goal of DR is to incentivize the desired behaviors of customers, producers, and prosumers while disincentivizing undesired usage behaviors. In the study of Alonso et al., the open automated demand response (OpenADR) mechanism is argued to successfully apply the PoC peak shaving scenario [12]. In the study of Nuur et al., continuously growing demand and high penetration of intermittent resources have become challenging issues, and the article proposes a game theoretic approach for DSM to reduce peak-to-average and smooth the dips [107]. Further, in the study of Pop et al., the Ethereum platform is used to self-enforce the smart contract that defines the energy flexibility of each prosumer and related reward/penalty mechanism [108]. Moreover, Stephent et al. analyze collective self-consumption, address measures to encourage consumers to participate in the DR and propose the consumption management of prosumers and consumers through BC [109]. Thomas et al. use a smart-contract-based DC control element to satisfy control instructions. Zhou et al. propose an encouragement method for EVs to enhance participation and maximize social welfare. Additionally, it is mentioned that central authorities like the DSO should be investigated in depth [110-85]. Ali et al. suggested that renewables and the energy storage integration of DSO-level aggregators be directed for DR purposes [111-112]. In Di Silvestre et al.'s study, load increment and reduction requests were notified by DSOs to provide flexibility to the system. The DSO communicates with each customer to reduce the usage proportionally by facilitating smart contract abilities 113]. In Edmonds et al.'s study, homeowners are required to send forecasted consumption patterns to the responsible DSO to reach a balanced power grid goal [114]. After aggregating the forecasted data, the utility solves the convex optimization problem of power balancing. Therefore, DSO and BC secure user privacy to encourage users to participate and balance the power grid. However, the timely forecasting and aggregation unleash scalability concerns. Cost-related DR was investigated in Canada, and Brown argued that the existence of DR induces electricity customers to consume more energy than the existing DR option [115]. Khajeh et al. addressed the DR problem at three points in the electricity network [22]. TSO-DSO-

Customer level flexible resources are mentioned as each level's system operator's deployment responsibility. The power of each branch and voltage of each node used is integrated, and after price customization calculations, the optimum power flow scheme is reached [116].

3.5.2 Blockchain for TSO/DSO Interactions

The requirements for determining the roles, needs, and guiding principles of the TSO/DSO interaction are highlighted in one study [117]. The hierarchical relationship between the TSO and DSO would be more horizontal in the future. In the old version of the grid, the DSOs have limited duties and responsibilities compared to TSOs. BC and rising distributed technologies will most probably influence bilateral interactions, such as power flow direction, grid responsibilities, and technical requirements. Additionally, DSOs have been considered responsible for voltage regulations, consumption billing, and customer operations, particularly for household customers. Contrary to the customary structure, DSOs will heavily burden other works such as frequency control, managing DG (solar, wind, etc.) participation, local markets, ancillary services, optimum power flow, and creating more democratizing grid structures henceforward [118-123]. However, TSOs would have interpenetrating and mutual duties and responsibilities against DSOs. TSOs may act as partners of future grid operations and transfer some liabilities, such as facilitating the power of DSOs and related DERs in possible blackouts. All these abovementioned situations were already inevitable, but heretofore with the emerging BC technology, these changes will speed up and be driven toward an ambitious ideal grid. Similar to all other grid shareholders, the TSO/DSO relation requires blockchain technology and its practical solutions [22].

3.5.3 Grid Capacity Investment Linkage with Blockchain

Electricity grid vulnerabilities against extreme weather conditions and federal funding opportunities that support grid resilience are highlighted in [124]. In addition, grid investments and BC collaboration are discussed under two topics. The first, as mentioned in the DR and EV subtitles, is mitigating the peak demand by encouraging users to participate in grid management by facilitating BC and smart contracts. Leveraging blockchain technology can reduce peak demand, thus reducing the DSOs' grid capacity increment investments. For a detailed clarification, the abovementioned subsections can be referred to accordingly. The other important subject of BC and grid investment is related to tracing grid investment and making it more transparent. In the vast majority of the world, the grid infrastructure is public property, representing an investment of billions of dollars. In underdeveloped low-income countries, the corruption level is much higher than in the rest of the world. In Ahmad et al.'s study, a blockchain-based custody evidence recording framework is highlighted to ensure the data reliability and prevent possible misconduct interventions. Shwetha et al. use a blockchain-based verification system to ensure commodity/food security through accountability in the public distribution system [125-126]. Alketbi et al. takes advantage of BC technology to deal with the data integrity of government services in a more secure way [127]. Hence, as a similar application, to prevent undesirable corruption, a smart contract structure would be extremely beneficial for pursuing and recording the investment details in an immutable and transparent way. All the grid investment auction details, payment details, competence of electricity contractor details, and useful economic life of the grid components can be traceable, owing to the unalterable BC technology. Despite the impossibility of entirely preventing corruption, tracking the relevant money and clearing the debate about public wastage by smart contracts would be a remarkable solution.

3.5.4 Blockchain for Environmentalism

Renewables are highlighted in tandem with carbon trading by Hua et al. and Keypour et al. [128-129]. Blockchain usage in SGs affects the environment in two ways: First, by encouraging participants to produce and consume low carbon energy, the CO2 emission level decreases [130-131]. Second, a possible mining procedure for BC may increase energy wastage. Carbon trading projects are environmentally friendly [6]. First, the carbon emission level may be measured, and all produced environmentally hazardous CO_2-equivalent green energy may be bought from the specific market using a smart contract. However, the carbon trading markets are considerably similar and appropriate to the distributed nature of BC; the application is in the initial stages owing to the computational constraints and response speed issues [132]. However, although the BC offers significant benefits, the amount of energy consumed in the mining process will amount to 45.8 TWh according to Vranken and Stoll et al. [133-134]. While the energy production methods mainly originate from fossil fuel sources, this is a vast figure for environmental concerns. In summary, despite computational constraints and response speed issues of BC in carbon trading, DSOs would play a crucial role because of their existing infrastructure.

Chapter 4

Investigation of Blockchain Potential for Pilot Region: DSM Perspective

The DSO is the most essential actor, as it is in charge of all grid operations and is the organization that keeps the grid running. The DSO's primary functions and responsibilities include grid maintenance and repair, grid troubleshooting, energy consumption billing, and compliance with all SG technical requirements. Another essential role of DSO is the implementation of grid capacity investments in order to meet grid needs within technological constraints. Every year, the increased use of new electric devices, the proliferation of new electricity generation facilities, and changes in user behavior force the technical boundaries and grid capacity. Increased population and consumption, particularly in fast-growing countries such as Türkiye, make grid capacity upgrades more crucial than ever. As noted in earlier sections, as the gap between generation and consumption widened, DSM arose as a major topic of grid management. In addition, Türkiye has recently experienced nationwide security of supply issues as well as extremely high energy prices. It illustrates that there is a significant need for controlling grid peak power by utilizing DSM techniques to secure the energy supply chain. This constraint can be overcome by utilizing magnificent BC technology. The electrical endurance capacity limit of the grid, as is well known, can be evaluated by measuring peak consumption and/or production power. For example, if a transformer's instant used power surpasses 100 kVA, it is required to select and install the transformer's maximum capacity, 160 kVA. Other transformer equipment, such as an electrical fuse, switch, cable, electric pole, utility box, and so on, must be chosen within new limits based on the transformer's limit adjustment.

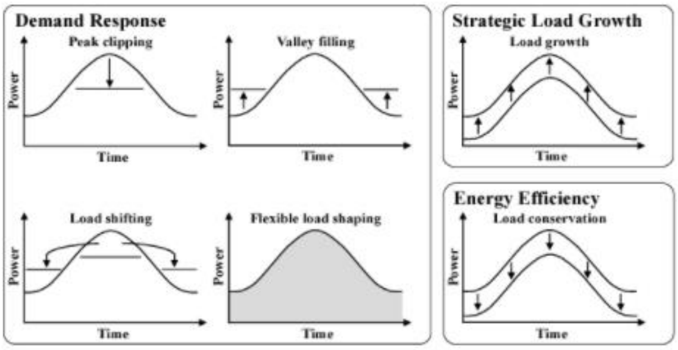

Figure 4.1 Types of DSM [160]

The DSM's primary goal is to minimize the peak power of the grid in a certain time span by employing various strategies. DSM studies employ a variety of strategies, including peak clipping, valley filling, load shifting, and flexible load shaping, as well as a combination of these methods, to achieve the lowest possible immediate power on the grid as it is illustrated in the Figure 4.1. Regardless of which researchers utilize these methods, the maximum instant power of the grid or one part of the grid will be reduced as a result. The demand for grid capacity enhancement investments will decrease regardless of the approach employed. In Türkiye, all grid investments collected from all electricity consumers or rather, all grid participants via electricity billing in general. As a result, more customers will be satisfied with less investments. In addition, reducing grid investments or wasting money reduces energy prices in the long-term. Because of its security and privacy-based structure, BC is the most effective way of employing the DSM project. This section will look into the advantages of employing BC in DSM studies. There are a number of potential positive effects of BC in a city that decides to adopt DSM on SG. The genuine peak power, the quantity of grid investment in the region, and the future anticipation of grid investment are all thoroughly investigated.

4.1 Overview of Pilot Region from the Point of Peak Power and Grid Investment

These grid investments can be collected under the some headings such as grid capacity, renewal, connecting line, lighting, and metering. Although it is very difficult to divide the content of the investment strictly, it is very obvious that capacity enhancement investment has lion's share.

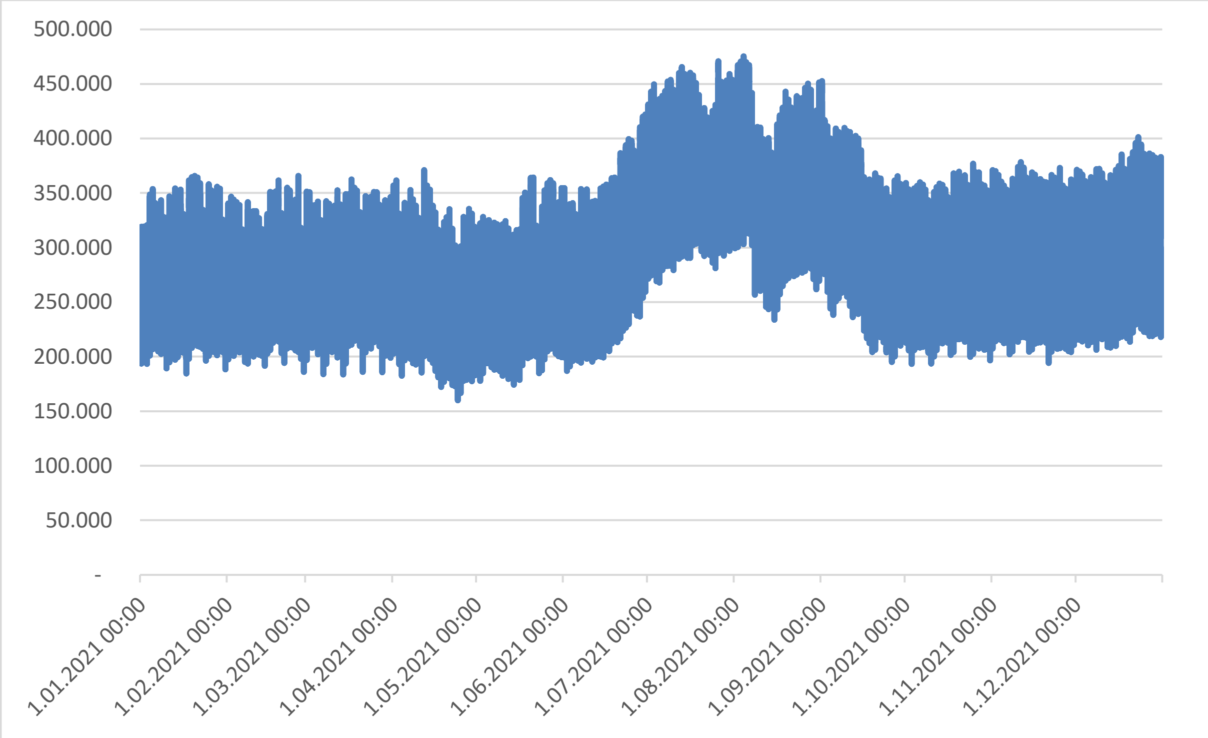

Figure 4.2 Historical Data of Hourly Consumption of the Region in 2021 (kW)

In this part, we will examine the investment costs of the region, their relationship with grid peak power and the potential positive effect of DSM using Blockchain (BC) technology. The region is a medium-sized city with a population of around 1.4 million people and a customer base of approximately 0.7 million people. Figure 4.2 illustrates historical statistics for the region's hourly consumption in 2021. In the time span, the summer peak output is 468 MW.

Table 4.1 List of Yearly Historical Grid Investments and Peak Power of the Region

Year	Summer Peak Power (MW)	Winter Peak Power (MW)	Total Grid Investment ($)	Grid Capacity Investment ($)
2011	343	301	27,630,933	18,175,453
2012	356	311	17,857,478	11,094,379
2013	379	320	30,222,599	18,636,234
2014	358	326	27,191,836	15,884,125
2015	381	359	14,690,688	7,097,856

2016	399	356	36,511,773	16,430,298
2017	436	356	44,379,483	19,083,178
2018	445	354	31,627,101	13,283,382
2019	435	350	21,164,465	8,465,786
2020	454	377	20,351,757	7,937,185
2021	468	374	30,220,576	11,483,819

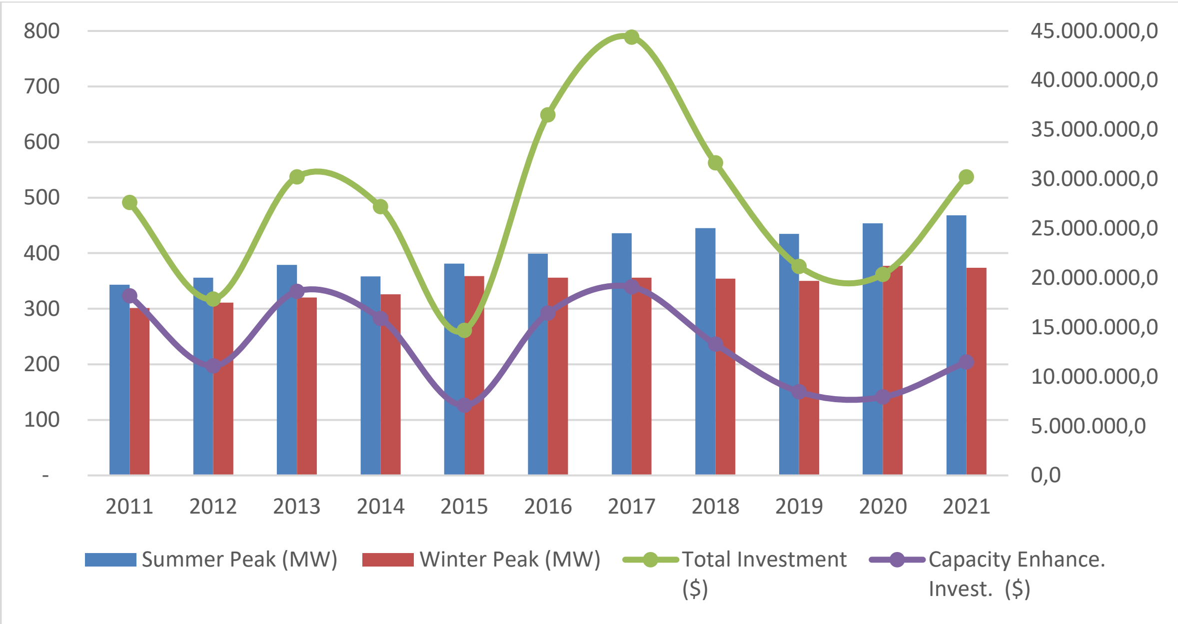

Figure 4.3 Historical Data of Grid Peak Power and Grid Investment

Table 4.1 shows a list of yearly historical data of grid investments and peak power in the region as a result of the region's expanding population and developing industry. The table shows the change in peak power from 2011 to 2021, as well as the grid investment based on that growth. While pilot region's highest power in 2011 was 343 MW in the summer, the peak power in 2021 will likewise be in the summer and will be 468 MW. During the same time span, winter peak power rises from 301 MW to 374 MW. Figure 4.3 shows that money was spent for 18,175,453 US dollars in 2011 and 11,483,819 US dollars in 2021.

In this study, time series used to forecast the future peak power of the grid. By acquiring the future peak power match and the amount of future grid investment matched it, that regulation institute (EPDK) determines in tandem with TSO (TEİAŞ) and relevant DSO. In order to analyze statistical data and to acquire the investment amount of money two different methods used. The first one directly related to the peak power of the entire grid. The peak power of the grid forecasted by using time series analysis and then the investment amount of money determined by assumption of utilizing DSM mechanism by using BC technology. Secondly, distribution transformers and their fill rate of each of them collected from the AMI software. Same DSM rates used to compare the saving amount of money and these two results compared.

4.2 Method 1- Forecasting the Peak Power

Future grid peak power is forecasted and compared with real grid investment data in this section. The peak power clipping techniques are then given, and it is assumed that if we reduce the peak power within the limitations of the literature by applying BC technology, what would be the overall savings, is found.

4.2.1 Time Series Background

Forecasting is a method of predicting real-world outcomes of future events using mathematical equations. The primary goal of forecasting is to foresee potential future scenarios. It is a duty in a forecasting research to determine the historical data and other facts that may impact the event. The forecasting approach may be determined by evaluating the data's behavior. The peak power itself is utilized as input data for the ARIMA model, as are peak power and several other parameters for the ARIMAX model development. Following that, the outcomes should be analyzed using performance criteria.

Time series can be classified as ARMA, ARIMA, ARIMAX, SARIMA, and SARIMAX according to the identified problem. In this part the ARIMA and ARIMAX are appropriate for the specific problem, when the SARIMA and SARIMAX are not because of their seasonality feature. Hereupon the ARIMA and ARIMAX models tested and the most appropriate solution accepted as the outcome. As forecasting performance criteria, mean absolute error (MAE), mean absolute percentage error (MAPE), mean squared error (MSE), root mean squared error (RMSE) are used. ARIMA and ARIMAX models compared with each other to find the model which gives minimum error. MAPE is the most common forecasting performance in studies in general and it is used to compare the outcomes. Minimum MAPE means the successful outcome is procured.

4.2.2 ARIMA (Autoregressive Integrated Moving Average)

This model represents statistical equilibrium between observations. Observation values vary around a fixed mean.

$$Y_t = \delta + \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \cdots + \phi_p Y_{t-p} + \varepsilon_t \quad (1)$$

For the Autoregressive Model (AR (p)), the dependent variable Y_t in equation 1 is; $Y_{t-1}, Y_{t-2}, \ldots, Y_{t-p}$ indicate the independent variables. Independent variables are lagged values of previous periods of the same (auto) variable. δ, constant term; ; ϕ_1, ϕ_2,…, ϕ_p are autoregressive parameters. The constant p, which takes an integer value, represents the degree of the model. ε_t is the error term, which is a zero mean, constant variance, uncorrelated random variable (white noise). This error term represents random fluctuations that cannot be explained by the model. If the p value and ϕ_1, ϕ_2,…, $\phi_p$parameters for which the equation is suitable can be determined, a suitable model for estimation will be obtained in Equation 1.

Moving Average Model (MA (q)) The value of the dependent variable Y_t the t period, the error or residual term(ε_t) in the same period, and the lagged values of the error terms of the previous periods ε_{t-1}, ε_{t-2},…, ε_{t-q} It is determined by $(t-q)$. Here q denotes the degree of the MA model. q. order MA(q) model is expressed by Equation 2.

$$Y_t = \mu + \varepsilon_t - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2} - \cdots - \theta_q \varepsilon_{t-q} \quad (2)$$

In Equation 2, μ is the constant term; θ_1, θ_2,…, θ_q are unknown moving average parameters, ε_t error term is white noise process. Equation 3 is obtained by rewriting the equation with the delay operator expressed by L, assuming μ=0.

$$Y_t = (1 - \theta_1 L - \theta_2 L^2 - \cdots - \theta_q L^q)\, \varepsilon_t$$
$$\Theta(L) = 1 - \theta_1 L - \theta_2 L^2 - \cdots - \theta_q L^q \quad (3)$$

For the Autoregressive Moving Average Model (ARMA(p,q)), the future values of the dependent variable depend on both the variable's past values and the past error terms. The ARMA(p,q) model is given in Equation 4.

$$Y_t = \delta + \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \cdots + \phi_p Y_{t-p} + \varepsilon_t - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2} - \cdots - \theta_q \varepsilon_{t-q} \quad (4)$$

The general form of the ARIMA (p,d,q) model is given in Equation 5. In the equation, ϕ_i denotes autoregressive parameter, θ_j denotes moving average parameter, ε_t denotes random term, p and q denotes autoregressive and moving average degrees, respectively. The delay operator is illustrated by Equation 6 using delay functions.

$$Y_t = \sum_{i=1}^{p} \phi_i Y_{t-i} + \sum_{j=1}^{q} \theta_j \varepsilon_{t-j} + \varepsilon_t \quad (5)$$

$$\Phi(L)\Delta^d Y_t = \Theta(L)\varepsilon_t \quad (6)$$

4.2.2.1 Performance of ARIMA Model

Winter and summer peak values of the region from 2011 to 2021 are used as input data for ARIMA time series model. Time intervals are assumed as independent values and winter/summer peaks are assumed as dependent values in the study. The ARIMA (2,1,2) model was obtained by using the time series data used for summer peak demand forecasting with the ARIMA model. In Table 4.2, the summer peak prediction success parameters of the ARIMA model are given. The ARIMA (2,1,1) model was obtained by using the time series data used for winter peak demand forecasting with the ARIMA model. In Table 4.2, the winter prediction success parameters of the ARIMA model are given. Error measures such as MAPE for summer and winter peak predictions of the ARIMA model were obtained.

Table 4.2 Performance of ARIMA Model for Summer/Winter Peak Power

Performance	MAE	MAPE	MSE	RMSE
ARIMA(Summer Peak)	7.467	1.926	74.649	8.640
ARIMA(Winter Peak)	7.066	1.990	57.501	7.583

4.2.3 ARIMAX

ARIMAX is a time series model that uses different time series values as input. Consequently, ARIMAX model forecasts by using more than one input variable in the model. The autoregressive model (ARX) with external variables can be expressed by

Equation 7. In the equation, X_t external variable(s), β coefficients of external variable(s), $\phi(L)Y_t$ AR model ($\phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \cdots + \phi_p Y_{t-p}$) shows.

$$Y_t = \phi(L)Y_t + \beta X_t + \varepsilon_t \qquad (7)$$

The moving average model (MAX) with external variables can be represented by Equation 8. In this equation, X_t external variable(s), coefficients of β external variable(s) and $\theta(L)\varepsilon_t$ MA model ($\theta_1\varepsilon_{t-1} - \theta_2\varepsilon_{t-2} - \cdots - \theta_q\varepsilon_{t-q}$) stands for.

$$Y_t = \beta X_t + \theta(L)\varepsilon_t \qquad (8)$$

The autoregressive moving average model (ARIMAX) with external variables can be expressed by Equation 9.

$$\phi(L)Y_t = \beta X_t + \theta(L)\varepsilon_t \qquad (9)$$

All abovementioned mathematical equations are used to achieve the future power of the grid. Therefore the amount of grid investment and its relation with the peak power will be used as part of the analysis.

4.2.3.1 Performance of ARIMAX Model

Winter and summer peak power values are evaluated separately in this section. The dependent value of the series is time variable and the number of Customers, total energy consumption of the region, minimum/maximum air temperature of the selected time period (from 2011 to 2021) are selected as independent input data of the dataset. Input variables of the model are shown in the Table 4.3.

Table 4.3 Input Variables of the ARIMAX Model

Year	Summer Peak Power (MW)	Winter Peak Power (MW)	Number of Customers	Total Consumed Energy (MWh)	Max. Temp. (°C)	Min. Temp. (°C)
2011	343	301	578,618	1,906,945	39.2	-18.5

2012	356	311	592,707	1,988,493	38.1	-17.7
2013	379	320	609,880	2,041,892	37.9	-21.5
2014	358	326	636,299	2,125,529	38.2	-11.6
2015	381	359	648,455	2,196,505	38.0	-20.9
2016	399	356	661,689	2,313,081	37.6	-20.2
2017	436	356	675,193	2,432,801	39.1	-19.3
2018	445	354	688,972	2,430,085	41.2	-12.9
2019	435	350	703,033	2,377,527	40.4	-16.8
2020	454	377	717,381	2,466,492	37.9	-19.7
2021	468	374	732,021	2,717,425	38.5	-16.8

By using dependent and independent time series variables the ARIMAX model run and ARIMAX(1,1,1) model gave the optimum result of the model. Also the optimum result for the winter peak power of the grid is chosen as ARIMAX(2,2,0). The performance of the model for winter/summer peak power are shown in Table 4.4.

Table 4.4 Performance of ARIMAX Model for Summer/Winter Peak Power

Performance	MAE	MAPE	MSE	RMSE
ARIMAX(Summer Peak)	5,259	1,392	67,142	8,194
ARIMAX(Winter Peak)	40,895	26,908	5151,940	71,777

Consequently, after comparison of the performance criteria of the model the ARIMA (2,1,2) model is chosen for summer peak and ARIMA (2,1,1) model chosen for winter peak, because of their MAPE value. Low, base and high forecasting result of the summer peak are shown in the Table 4.5. Also low, base and high forecasting result of the winter peak are shown in the Table 4.6. Base is the essential result but low and high results are added as of demonstrating the flexibility of the model within +/- 2%. Also the yearly changes are indicated in the same table.

Table 4.5 Output of the ARIMA (2,1,2) model for Summer Peak Power (MW)

Year	Forecasted Data (Base)	Forecasted Data (Low)	Forecasted Data (High)	Yearly Change (%)
2022	480	470	490	2.57
2023	497	487	507	3.54
2024	510	500	520	2.62
2025	519	509	529	1.76
2026	533	522	544	2.70
2027	545	534	556	2.25
2028	560	549	571	2.75
2029	570	559	581	1.79
2030	587	575	599	2.98
2031	597	585	609	1.70

Table 4.6 Output of the ARIMA (2,1,1) model for Winter Peak Power (MW)

Year	Forecasted Data (Base)	Forecasted Data (Low)	Forecasted Data (High)	Yearly Change (%)
2022	369	362	376	1.01
2023	372	365	379	0.81
2024	382	374	390	2.69
2025	392	384	400	2.62
2026	391	383	399	-0.26
2027	394	386	402	0.77
2028	399	391	407	1.27
2029	406	398	414	1.75
2030	407	399	415	0.25
2031	410	402	418	0.74

In normal conditions, the time series model's output expected to be realized in the future. Additionally the investment values are determined and informed by regulation institute. As it is known the determination of the amount of investment money determined by using all DSO's process reports of grid events and needs. Hereby, the budget can be transitively affect previous and next year's investment, but it can be ignored in this general approach. The obtained values of summer/winter peak power, the total grid investment and capacity enhancement investments are shown in the Table 4.7. The base winter power never surpasses the summer peak power. Therefore, only the summer peak power, the greater one, will affect the investment amount of money the most. The total investment and the contribution of grid capacity enhancement in it are shown in the Table 4.8 with the forecasted summer/winter peak power.

Table 4.7 Yearly Forecasted Peak power and investment amount of money

Year	Summer Peak (MW)	Winter Peak (MW)	Total Investment ($)	Capacity Enhance. Invest. $
2022	480	369	16,129,032	5,967,742
2023	497	372	15,243,902	5,487,805
2024	510	382	14,501,160	5,075,406
2025	519	392	13,616,558	4,629,630
2026	533	391	16,900,048	5,577,016
2027	545	394	15,909,091	5,090,909
2028	560	399	15,217,391	4,869,565
2029	570	406	14,000,000	4,410,000
2030	587	407	13,461,538	4,173,077
2031	597	410	12,962,963	4,018,519

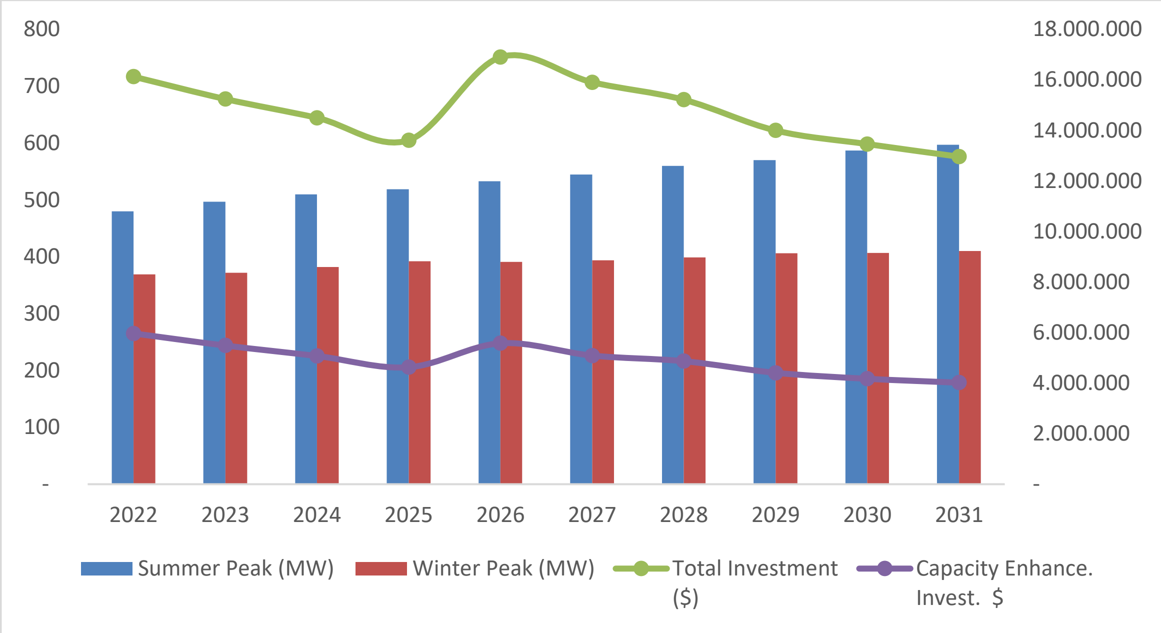

Figure 4.4 Forecasted Data of Grid Peak Power and Grid Investment

Consequently the peak power and peak power related amount of grid investment are obtained. It is known that how much money grid needs to spend in near future. Therefore the relation between the peak power and grid investment seen more obviously in the Figure 4.4.

By studying on the peak power and grid investment our main intention is to obtain the total saving of DSO when the BC based DSM project applied on the entire grid participants. The rest of the thesis, the DSM in the literature surveyed and an estimation in process of using the peak load clipping method investigated.

The purpose and optimization method of the Demand side management programs can be classified as minimization of electricity cost, maximization of social welfare, minimization of aggregated power consumption [161]. It is demonstrated that 5.9% of peak demand in a typical large city can enhance power system. The experiment conducted on a summer day when the peak demand is 7.5 GW and the total amount of controllable load is 0.87 GW [162]. The total demand response potential in Finnish large scale industry is determined at about 9% of entire power system [163]. Synergychain mechanism used to cluster the prosumers in order to enhance scalability and performance of the system. Also, BC based FederatedGrid mechanism demonstrates the reduction of the load of the utility grid is 13.6% and decrease in the energy cost is 17.8% in a decentralized P2P energy trading microgrid [164]. The peak average load decrease in residential load is 14%, in commercial load is 16%, and in industrial load is 10% [165].

In the region half of the total consumed energy is coming from AMI customers and these customers are very appropriate for BC because of their existing structure. Therefore these AMI customers, in other words industrial customers considered as the main objective of this study. Thus the peak clipping methods assumed to apply to the entire grid under three different levels. DSM levels and potential new summer and winter power levels are shown in the Table 4.8. The highlighted values are representing the year that grid reachs the existing peak value in the table.

Table 4.8 Yearly new peak power when DSM applied

Year	5%		10%		15%	
	Summer Peak (MW)	Winter Peak (MW)	Summer Peak (MW)	Winter Peak (MW)	Summer Peak (MW)	Winter Peak (MW)
2022	456	351	432	332	408	314
2023	472	353	447	335	422	316
2024	**485**	363	459	344	434	325
2025	493	372	467	353	441	333
2026	506	371	**480**	352	453	332
2027	518	374	491	355	463	335
2028	532	379	504	359	**476**	339
2029	542	386	513	365	485	345
2030	558	387	528	366	499	346
2031	567	390	537	369	507	349

The maximum power of the grid shrinks from 480 MW to 456 MW if the 5% DSM applied, hence the peak load of the entire grid falls to a new level. Thus, the peak load can reach the existing level seem to be in two years. Also beginning from 2022 to 2031 all years calculated based on 5% decline. Additionally assumption of applying other levels like 10% and 15% give result of new peak values. Similarly applying 10% decline, thanks to the DSM, result in 432 MW for 2022. The new calculated level may reach the real 2022 level within four years. On the other hand, by applying 15% decline results new peak power and as it is seen the arrival of real 2022 peak power lasts 6 years. That means there is no need for the past 6 year's grid capacity enhancement investments in other words. In sum, the total saving of BC based DSM's can be calculated by summing up yearly amount of capacity investment.

The total consumption quantity of all Customers and contribution of AMI Customers in it for the region is given in the Table 4.9. It is obviously seen that AMI Customer's consumption quantity creates approximately 43% of total consumption. In addition to that, number of all consumers is 732,021 as of 2022 and number of AMI consumers is 9,832.

Table 4.9 The Consumption, the number, and the Consumption Rate of AMI of All Customers

Year	Total Cons. (MWh)	AMI Cons. (MWh)	AMI Cons. Rate in Total	Number of All Customers	Number of All AMI Customers
2015	2,196,505	894,754	41%	648,455	4,519
2016	2,313,081	1,013,577	44%	661,689	6,030
2017	2,432,801	1,070,626	44%	675,193	7,025
2018	2,430,085	1,051,016	43%	688,972	7,752
2019	2,377,527	1,017,571	43%	703,033	8,089
2020	2,466,492	1,068,889	43%	717,381	9,156
2021	2,717,425	1,242,904	46%	732,021	9,842

The calculated saving can be divided in two parts, one the total saving and second the potential saving share of industrial AMI customers in it. These AMI customers are more appropriate than other common ones, because of their existing smart meter. Hence, the potential total capacity investment saving amount of money in US dollars and the share of AMI consumers are calculated and listed in Table 4.10. In the table savings comprises lower saving, that means, 10% involves 5% and 15% involves 10% as well.

Table 4.10 Total savings according to the DSM rate and Customer type.

	Total Savings	
Rate of DSM	All Customers ($)	Only AMI Customers ($)
5%	11,455,547	4,925,885
10%	21,160,582	9,099,050
15%	31,828,508	13,686,258

The results show that relatively high amount of money can be saved. Only 5% decrease in the peak value of the city grid means approximately 4,925,885 US dollars saving.

4.3 Method 2- Generalization

Under this section the peak value of each transformer handles separately in order to reach the total investment amount of money. Each transformer and its load factor considered as input data according to nominal power rate. The number of existing transformers and their load factor listed in Table 4.11. All levels of the transformers divided in to different rates as 95%, 90%, 85%, 80%, and 70%. Then the approximate costs, which would use to enhance capacity, calculated by using real field grid projects. The other investments like illumination, energy transmission, and Customer capacity enhancement are neglected and only AMI Customers' data are used. The mean cost of each transformer rate is calculated by using three similar capacity enhancement project's cost sheet.

Table 4.11 Number of Distribution Transformers and Capacity Rates

	Number of Transformers (AMI Customers)						
Power of Transformer	100% to 95%	95% to 90%	90% to 85%	85% to 80%	80% to 70%	70% to 0%	Total
50 kVA	7	14	3	3	7	260	294
100 kVA	8	10	4	5	12	537	576

160 kVA	6	7	1	2	6	324	346
250 kVA	5	6	6	4	11	325	357
400 kVA	6	5	3	1	22	307	344
630 kVA	3	8	6	5	20	334	376
1000 kVA	1	2	0	0	5	69	77
1000 kVA (Above)	0	0	1	0	0	17	18

To make it more understandable and appropriate to method-1, the fill rate and the number of transformers classified by fives. The numbers give the real distribution transformers in the real existing grid. Nevertheless the number of all AMI Customers are more than this number, because of that some customers do not have any transformer.

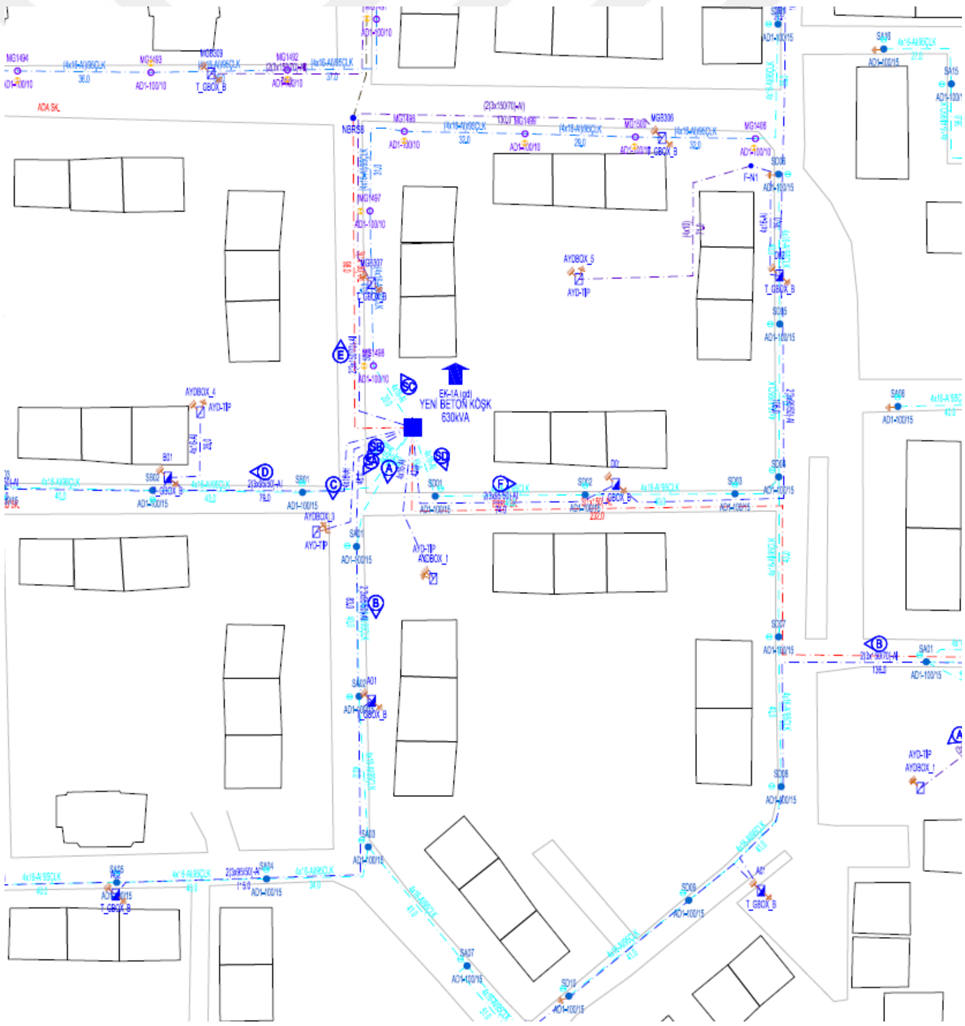

Figure 4.5 Sketch of an Electricity Distribution project of a 630 kVA transformer in the Region

The Figure 4.5 represents small part of a project of 630 kVA transformer. Calculation of cost of all other transformer rates made by this kind of real field applications. In this project, underground high/low voltage cables are used and also majority of the customers consist of household customers as well.

Table 4.12 Cost of Distribution Transformers and Capacity Rates

	Costs		
Power of Transformer	Only Transformer ($)	Transformer with Grid Installation ($)	Disassembly ($)
50 kVA	49,026	454,716	27,898
100 kVA	65,368	461,398	32,714
160 kVA	71,487	606,288	37,197
250 kVA	141,853	1,261,844	62,061
400 kVA	158,124	1,294,109	18,832
630 kVA	208,097	1,218,848	61,678
1000 kVA	260,121	1,423,560	77,098
1000 kVA (Above)	312,146	1,828,272	92,517

Calculated mean cost of each transformer rates are given in the Table 4.12. The economic value of each transformer type changes by the region, used equipments, and that project applied. Most of the time the calculated values are gradually increasing as it can be seen. However, some cost of the applied project may change due to abovementioned changes.

Table 4.13 Cost of Each Transformer Power Rate ($)

	Cost of Each Transformer Power Rate ($)		
Power of Transformer	From 100% to 95%	95% to 90%	90% to 85%
50 kVA	421,760	843,520	180,754
100 kVA	642,682	803,352	321,341
160 kVA	370,121	431,808	61,687
250 kVA	826,408	991,689	991,689
400 kVA	983,476	819,564	491,738

630 kVA	479,598	1,278,927	959,196
1000 kVA	187,348	374,696	-
1000 kVA (Above)	-	-	239,799
Total	3,911,393	5,543,556	3,246,204

The capacity rate of each transformer power and total of each section is given in Table 4.13. As it is seen in the table, 5% decline in entire transformer user's capacity means 3,911,393 US dollar investment doesn't needed. Similarly the 10% peak load clipping means 5,553,556 US dollars less additional investment needed. And lastly 15% correspond to 3,246,204 saving in general. Reasoning and deduction methods gives the approximate results. In other words, second method proves that the output of first method is also true as it is seen in Table 4.14.

Table 4.14 Comparison of two methods' outputs

	Comparison of Total Saving of Each DSM Rate ($)		
Method / DSM Rate	Reduction (5%)	Reduction (10%)	Reduction (15%)
1. Method (Time Series)	4,925,885	9,099,050	13,686,258
2. Method (Reasoning)	3,911,393	9,454,949	12,701,153

In this section analysis the greatest part of the DSO, the capacity enhancement investments, and how would it be decreased by using BC's promising technology. As specified in the previous pages, both of the methods promote each other in results. Nowadays, particularly in these pandemic years all of the world contemplates on saving money. Less costly solutions and more money saving seems as rescuer of all sectors, especially energy sector. In energy sector, DSM solutions are more investment saving options in the modern world. In the first place, applying DSM projects applicable if and only if possible by utilizing BC-based systems because of its decentralization, transparency, security and privacy features. Also the trust in financial sector encourages all energy participants to be a part of this secure system. BC solution may reduce the cost of energy itself and cost of transferring it. Hence, the energy efficiency will be increased and more importantly the security of supply will be ensured, thanks to the BC.

4.4 Cost of Marketing Fee of the Region

The marketing fee is a cost especially for DSO to pay the central marketing authority on condition to keep alive the system. Apart from making it central, the existing marketing system causes security concerns. By putting in to use of BC technology, all grid participants will get rid of extra expenses. The yearly marketing fees of the region, from 2018 to 2021, are given in Table 4.15. The total payment of the region is 249,740 US dollars.

Table 4.15 Yearly Fee of Marketing Operation

Year	Marketing Fee ($)
2021	43,590
2020	64,897
2019	65,327
2018	75,927
Total	249,740

By creating decentralized BC system, the marketing fee will not be valid anymore and the money will be some kind of profit for companies.

Apart from BC's other magnificent solutions offerings, applying on a small scaled city's distribution grid creates great amount of saving as well. BC has great potential to embrace all electricity users, on the other hand the economic saving draw attention of DSO the most.

4.5 Variable Costs of Applying Blockchain Project

There will be some costs of transition from old to modern, such as operating expenses, communication expenses, and hardware costs in general. However, these cost directly or indirectly related to the selected CA. Without determining the CA, that will affect the BC system in many ways, it is very difficult to determine real cost of the BC. For instance the hardware dependency changes CA to CA, and also communication infrastructure may change depend on the pilot projects expectation. Nevertheless, existing hardware configurations and communication substructure of AMI users will most likely create wonderful convenience. Exact costs analysis can be determined by applying BC in a real field project. On the other hand the legal regulation most likely puts in order the development process and the responsibility of DSO and customers, so the limits will be determined strictly.

Consequently, the grid investment is the greatest expense of DSO and this cost directly affects electricity prices and thereby the users. Reducing peak load has significant positive impact on every participant of the grid. Combining the magnificent features of BC with DSM methods most probably results spectacular positive outcome. As it is demonstrated DSOs have to be prepared and to be eager on new era with the help of legal regulations.

Chapter 5

Energy & Blockchain in Türkiye

5.1 YEK-G (EXIST)

National energy market of Türkiye, Energy Exchange Istanbul (EXIST), created blockchain-based YEK-G system, to promote renewable energy sources (RESs) in electricity generation and consumption as an enviromentalism project. The main aim of the system is not only to manage energy exchange in the grid, but also to manage the generated licensed legal entities from clean energy sources. Documentation of RESs guaranteed consumers to obtain electric energy. Operation of the system is in a non-discriminatory, objective, and transparent manner. The participation of the YEK-G system propesed as voluntary basis. A network implemented where blockchain technology can be used actively in energy markets by investing in the future with innovative technologies.

The tracking of certificates will be facilitated by blockchain technology, as well as the creation of an innovative, safe, and transparent market environment. The first domestic blockchain network of energy markets established via this blockchain network. With the trading and disclosure of renewable energy certificates via the network, it verifies that final users are obtaining their energy from renewable energy resources. The YEK-G System's aim is to record and document the source of energy consumed by final consumers and supply firms by recording and documenting the characteristics of each 1 MWh of energy delivered to the network by the system's producing facilities. Transactions for the buy, sale, redemption, and float of renewable energy certificates will be made using blockchain technology thanks to the platform to be developed by EXIST. Development process of YEK-G project is illustrated in Figure 4.1. Also issued quantity of Yek-G documents in MWh from 15/06/2021 to 19/11/2021 is listed in Table 4.1.

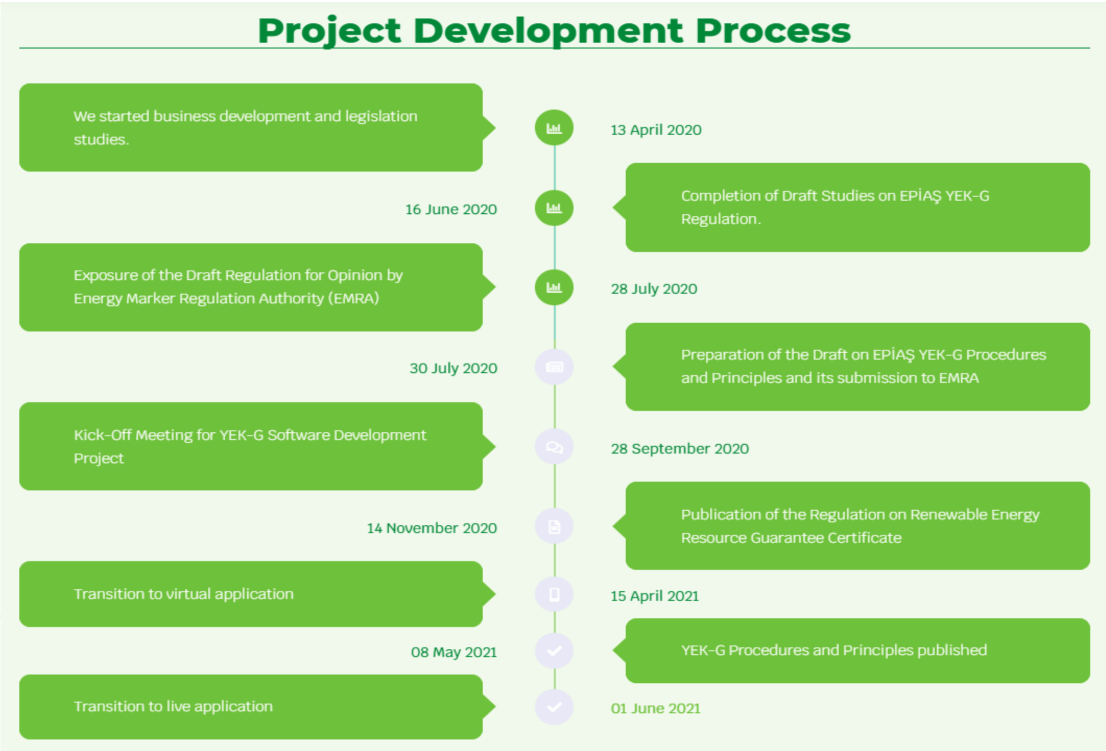

Figure 5.1 Development process of YEK-G project [154].

Table 5.1 Issued quantity of YEK-G documents in MWh from 15/06/2021 to 19/11/2021 [157]

Date	Wind	Solar	Hydro	Jeotermal	Biomass	Total
15.06.2021	0	0	0	85,593	0	85,593
16.06.2021	28,141	0	46,761	0	0	74,902
17.06.2021	2,433	0	5,038,788	0	0	5,041,221
18.06.2021	0	0	71,977	0	1	71,978
21.06.2021	10	0	567,048	31,75	16,738	615,546
22.06.2021	0	0	4,355	170,783	0	175,138
24.06.2021	0	0	5	107,083	0	112,083
28.06.2021	8,948	0	20,852	0	0	29,8
29.06.2021	0	0	3,987	45,09	0	49,077
1.07.2021	0	0	1	0	0	1
2.07.2021	0	0	1	0	0	1
6.07.2021	0	0	6,754	0	0	6,754
9.07.2021	0	0	5,923	0	0	5,923
12.07.2021	0	0	50	0	0	50
13.07.2021	0	0	0	0	2,827	2,827
14.07.2021	0	0	71,909	0	0	71,909
16.07.2021	0	0	23,789	0	0	23,789
26.07.2021	0	0	7,508	3,585	0	11,093
27.07.2021	0	0	23,452	0	0	23,452
28.07.2021	3,32	0	92,781	0	9,247	105,348

29.07.2021	100	0	158,474	91,263	100	249,937
30.07.2021	6,437	0	515	0	0	6,952
9.08.2021	0	0	3,351	0	0	3,351
10.08.2021	8,321	0	0	0	0	8,321
16.08.2021	0	0	6,126	0	0	6,126
17.08.2021	0	0	23,539	3,241	0	26,78
18.08.2021	0	0	3,784	0	0	3,784
19.08.2021	0	0	3,112	165,706	0	168,818
20.08.2021	24,362	0	193,254	0	7,087	224,703
26.08.2021	0	0	100	64,594	0	64,694
31.08.2021	0	0	5,561	0	0	5,561
14.09.2021	0	0	6,198	0	0	6,198
16.09.2021	0	0	3,923	0	0	3,923
17.09.2021	0	0	5,283	0	0	5,283
20.09.2021	10,103	0	124,59	0	0	134,693
21.09.2021	0	0	164,017	34,024	7,556	205,597
22.09.2021	4,446	0	9,109	0	0	13,555
29.09.2021	0	0	0	83,508	0	83,508
7.10.2021	0	0	368	0	0	368
13.10.2021	0	0	349	0	0	349
18.10.2021	0	0	10,501	0	0	10,501
21.10.2021	16,561	0	397,717	0	15,001	429,279
22.10.2021	0	0	15,795	0	0	15,795
25.10.2021	6,263	0	0	0	0	6,263
27.10.2021	0	0	504	0	0	504
1.11.2021	0	0	10,102	0	0	10,102
2.11.2021	0	0	1,605	0	0	1,605
3.11.2021	0	0	16,221	0	0	16,221
5.11.2021	0	0	0	81,793	0	81,793
9.11.2021	0	0	8,935	0	0	8,935
10.11.2021	0	0	2,34	0	0	2,34
18.11.2021	9,753	0	15,228	0	0	24,981
19.11.2021	4,077	0	363,878	70,592	3,029	441,576
Total:	**133,275**	**0**	**7,545,415**	**1,038,605**	**61,586**	**8,778,881**

5.2 Foton Energy & Energy Web

Foton is a Turkish energy innovation firm that was formed in the Innovation Center of the Energy Exchange Istanbul in 2019. By creating a local digital renewable energy purchase marketplace, Foton is expediting Türkiye's energy transition. The Foton team has substantial energy trading and origination knowledge. Foton is a member of the Energy Web. Foton energy announced that 4,918,135 MWh energy certificated and exported by using blockchain technology until 06/12/21 [158].

Foton, a startup in the energy transition, and Energy Web (EW) announced the launch of a first-of-its-kind commercial pilot for renewable energy trading in Türkiye. The International REC Standard, the energy attribute certificate (EAC) standard in more than 30 nations around the world, is aligned with Foton's digital, blockchain-based platform for tracking and selling international renewable energy certificates (I-RECs).

In April 2020, Foton and EW released the first version of the Turkish I-REC platform after seven months of development. In order to safely acquire correct power generation data, the renewable energy trading platform has already integrated with the open Energy Exchange Istanbul (EXIST) infrastructure. EXIST oversees monitoring and operating Türkiye's energy markets, which includes ensuring that market conditions are transparent, reliable, and trustworthy, as well as providing equal access to all market participants. Following that, in August 2020, a trial will take place in which several significant renewable energy suppliers will use Foton's platform to register I-REC assets such as solar and wind farms and sell I-RECs directly to buyers.

5.3 Blok-Z

Blok-Z used their token engineering skills, partnerships, and close relationship with ConsenSys, as well as its knowledge of market mechanisms, to create GreenLink, their first product that tracks local renewable energy for energy providers. Several customers confirmed the product's necessity.

Blok-Z also provides end-to-end blockchain services to handle all of your enterprise blockchain onboarding requirements, from initial set-up to blockchain and business strategy development. All outsource needs of your blockchain, such as non-custodial smart wallets, which allow you to manage and maintain full control of your digital assets using enterprise-ready multi-signature wallets, set up private chains, or run a node on the public blockchain, meets the requirements. It is claimed that, all of solutions help energy companies, consumers, and prosumers by lowering operational costs, automating back-office processes, and increasing transparency.

One of the products of Blok-Z Company is GreenLink. GreenLink is a white-label blockchain platform that enables energy retailers to provide truly sustainable and individualized digital energy services to their customers. Customers of GreenLink-enabled energy retailers will be able to choose renewable sources based on location/distance and type, track the origin of their energy in real time, and access automated sustainability tools. GreenLink adds value to energy providers by unlocking new revenue streams from value-added energy services, increasing customer acquisition and retention as a result of increased trust in their green energy services. Some proposed features of Blok-Z are illustrated in Figure 4.2.

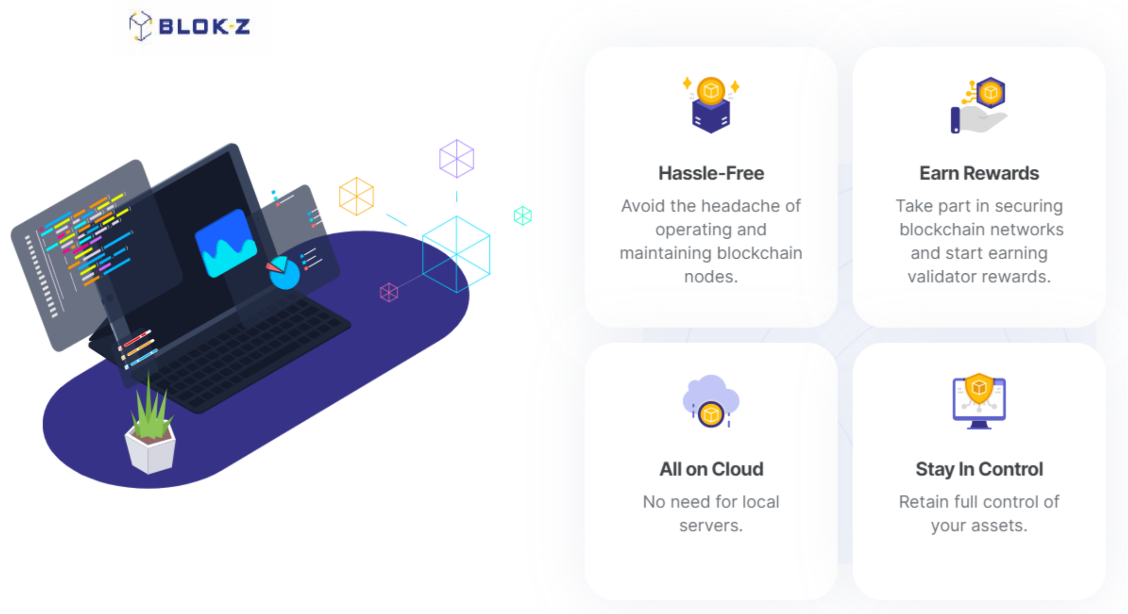

Figure 5.2 Features of Blok-Z [155].

5.4 Inavitas & Energy Web

Inavitas is at the forefront of smart energy monitoring and management solutions for energy systems of all sizes. In terms of consumption and even production, inavitas provides real-time monitoring, control, and analytical tools for use in both commercial and residential energy systems. Inavitas provides workforce management tools, production/distribution optimization tools, and state-of-the-art SCADA systems to industry players in renewable energy production and smart grids, including turnkey design, training, and installation.

Inavitas, an energy intelligence company with offices in Australia, India, and Türkiye, has joined Energy Web as its newest member and plans to host an Energy Web Chain validator node. Inavitas provides digital solutions for customers ranging from utilities to large renewable energy generators to homes and businesses, such as SCADA integration, cost reduction, and renewables optimization.

Energy Web is a global, member-driven nonprofit that uses open-source, digital technologies to accelerate the low-carbon, customer-centric energy transition. We enable any customer's energy asset to participate in any energy market. The Energy Web Chain, the world's first enterprise-grade, public blockchain tailored to the energy sector, serves as the foundation of our technology stack. Leading utilities, grid operators, renewable energy developers, corporate energy buyers, IoT / telecom leaders, and others comprise the Energy Web ecosystem. The EU supported logo of strongest climate impact award of Inavitas is illustrated in Figure 4.3.

Figure 5.3 Strongest climate impact award of Inavitas [156].

5.5 Flexigrid & OEDAŞ

To achieve the goal of flexibility in the grid, OEDAŞ created an integrated architecture of the grid. Electricity market, interaction between DSO, TSO, producers, and consumers structures created to reach the overall CO_2 emission level. The main staff that handled within this project is EVs. In the process covering the first interim report period, system architecture development studies were carried out together with OEDAŞ in line with the contribution and needs of other stakeholders. In the process covering the second six-month interim report period, a username and password were defined for the partners in order to perform the display and transactions for the developed blockchain-based platform. Thus, the partners tested the P2P energy trading platform using their sample wallets. For example, flexibility can be requested, and at the same time, flexibility has been purchased via blockchain with a defined cryptocurrency wallet. The existing flexibility assets of the partners will be integrated into the P2P platform, and at the same time, their current flexibility needs and insights will be monitored through the platform. Evaluations and development studies for the P2P platform, which was first shown within the scope of the work package, of which OEDAŞ is also a pilot partner, continue. Trying to realize the energy transfer technology from the vehicle to the grid and the use of battery storage system with pilot studies in order to increase the network flexibility, OEDAŞ determines a pilot region in the Eskişehir distribution region and carries out studies to fulfill the technical requirements.

5.6 Akedaş

The aim of the project is indispensable for the realization of 100% renewable energy in electricity grids. Cloud-based multi-layer optimum aggregator for demand management (DR) and grid resilience (aggregator) solutions and to develop legislative proposals. EU ERA-NET Smart Grids Plus Program includes demand control solutions in three different layers, which can include the unavoidable combiners for it. It is aimed to develop mechanisms and software platforms to support these mechanisms. Multi-disciplinary work such as network flexibility, demand-side participation, cloud-based solutions and smart contracts an international consortium has been formed as it is a project involving.

5.7 Aras EDAŞ

The aim of the project is the development of a secure, transparent digital timestamp platform that includes a decentralized consensus mechanism and cryptographic algorithms in a blockchain-based, distributed database architecture specific to the electricity distribution industry.

5.8 Gdz EDAŞ

In the related project, it is aimed to create a digital identity card for an asset by taking advantage of the blockchain technology, to track the asset with an unchangeable record from birth to death, and to control these records in electronic environment in a transparent manner by regulatory/supervisory institutions. The current values of the assets can be tracked on the same platform, and it will also be possible to view which asset the maintenances will be matched with and how much total cost has been spent for that asset. If there is an IoT system on these assets, the asset status can be followed up-to-date by communicating instantly with this platform. In addition, the project to be carried out with a local team in Türkiye aims to be among the top 5 companies in the world's blockchain asset management software ecosystem.

5.9 Başkent EDAŞ

In the project Enport, it is planned to design a decentralized-distributed application using blockchain technology, with a completely innovative approach, instead of classical web service and application software. Creating end-to-end content needed by distribution companies and their employees by making use of the advantages of blockchain technology. For all DSO employees' identity card will be provided and access to the portal by ID will be provided. Therefore, the possible problems and solutions for vocational trainings, social responsibility projects, R&D projects, and investment projects will be handled quickly. It is aimed to privately identify the problems of the sector with surveys, and to make a service that includes the revolutionary innovations brought by the blockchain technology as a result of the project, to serve all the stakeholders of the sector.

5.10 Some Other Blockchain Related Institutions

5.10.1 Havelsan

HAVELSAN is a large-scale software firm that researches and adapts emerging technologies. Because of its numerous benefits, blockchain technology has become one of the next generation technologies that HAVELSAN is interested in. HAVELSAN's activities are diverse, thus the company can create a variety of Blockchain-based applications based on these fields. Because of this diversity, as well as the relevance of the Smart Contract concept, which may be regarded the foundation for most Blockchain applications, it was determined to construct a powerful Smart Contract framework before beginning to build diverse Blockchain applications [140]. The ability to integrate is perhaps the most significant issue that has arisen throughout the development of the program. Although the Hyperledger Fabric and Cello tools may be used to create a high-security, flexible, modular closed-box Blockchain network tailored to a customer's demands, there are limitations in terms of interaction with external systems.

5.10.2 TÜBİTAK Research Laboratory

In December 2018, besides the establishment and working principles, the roadmap for the installation of laboratory was worked on. Which was held with the participation of TÜBİTAK BİLGEM Blockchain Research Laboratory, Gebze Technical University, Kadir Has University, Istanbul Commerce University, Antalya Science University, Istanbul Gedik University, Ankara Yıldırım Beyazıt University, Konya

Necmettin Erbakan University academicians and TÜBİTAK B3LAB. It was decided to complete the the technical infrastructure installation works and put the BAĞ system into practice.

The system will be created by adding a certain hardware and network infrastructure resource to the system by each member organization. BAĞ ecosystem aims to offer environments where multiple technologies can be tested, rather than testing a single technology compared to its counterparts called TestNet, and to enable participants to jointly share academic research, development, training and information on these systems. After the core system is established, the Blockchain Research Network, which aims to expand with the participation of other universities, public institutions and private sector organizations interested in the subject, is considered to be a system that will be implemented for the first time in the world with its many features.

It offers services where researchers can work on blockchain, test their output, and shape project ideas with researchers [159].

Chapter 6

Conclusions & Future Prospects & Discussion

6.1 Discussion

Erturk et al. investigated the positive and negative impacts of the application of BC in smart energy [135]. Beneficial impacts are classified as improved system security, increased data privacy, removal of intermediaries, and immutability, whereas adverse effects are sorted as scalability, cost of establishment/maintenance, and the need for further studies [136]. Finally, it is recommended that economic feasibility and other costs should be studied. However, the BC in the energy sector, especially the EV and prosumer sides, did not prove to be an entirely secure and privacy-preserving solution. Significant challenges to application are the cost of integrating the new BC-based technology with existing devices and the convenience level of the grid framework [37]. To this end, the hardware cost of the BC-enabled counterpart of the grid management, monitoring, and measuring devices is still extremely expensive, and further research is required to achieve complete adoption of BC in the power grid [6]. The demand for communication and data processing will increase steeply because of the steepest increase in the quantity of transaction data, simultaneous energy trading of participants every second, and an increase in the number of network users. In addition, instant changes in the network will require researchers to investigate less-data-costly options, such as side chains [9-24]. Blockchain technologies in SGs are categorized as demand response (DR), EVs, IoT, decentralized energy management, environmentalism, energy trading, finance, and cybersecurity [8]. Kulkarni et al. viewed BC technology as a solution to the problem of a lack of electrification in rural areas because of its low cost and accurate transaction opportunity [137]. Issues and challenges that SG faces are as follows: mistrust in the industry, vulnerability to security threats, functionality and low penetration of EVs, frequency and voltage problems due to grid imbalance, and lack of standardization [138]. The concept, structure, architecture, and trading mechanism of "Energy Internet" have been discussed. However, the transaction costs are claimed to remain an obstacle, but utilities can promote such transformation [28].

All DSO-related energy parties are listed, and the short-term applicability levels in a general blockchain are interpreted in Table 5.1. Apart from local projects and those containing only one type of grid user, in the condition called general BC expresses the environment that containing all electricity users in one place or nested BC environment as well. SCADA and AMI are the main grid management and monitoring technologies for DSOs. The central operation part of the SCADA system has high computational power, but the distributed parts of the SCADA and AMI must lack computational power. In addition, neither DSO unit requires intensive mechanisms to participate in the blockchain system. While communication is not an issue for SCADA, smart meters' communicational power should be enhanced, and new expensive hardware investments are thus required [139]. This investment should be undertaken by the DSO, for which the motivation must be specified. Meanwhile, SCADA has a centralization issue, but AMI systems are highly decentralized. Therefore, as all aspects of both grid components are considered, both SCADA and AMI nodes are noted as having medium-level applicability in the short term. EVs most likely have substantial computational power arising from smart cars and CFUs. The EV environment is most likely the pioneer unit, even a forcing point for the encouragement of new BC implementation in the near future. Owing to EV circulation worldwide, the desire for BC will increase. However, with the dilemma that while an incentive mechanism can be implemented to charm all EV users into participating in the system, this may have harmful negative effects on the grid. Therefore, these unintended conditions may be self-destructive, and it is difficult to enhance EV usage. Nevertheless, the need for a privacy-preserving environment for EVs and the demonstration of existing EV projects indicate its applicability level as high in the short term. Conversely, the up-to-date requirements for computational power of microgrids "and DERs" are generalized and categorized as medium level. Given the established place and exact situation for all DERs and microgrids, it is a bit harder to determine the exact situation for all DERs and microgrids. Although self-sufficient microgrids are highly appropriate for BC frameworks because of their local and minimal conformation, self-contained nature, and limited need for an on-grid system, the participation of microgrids in a widely established BC environment is a challenging situation. Therefore, its applicability is seen as medium level. Marketing and demand response do not require additional computational power because of the inclusiveness of other BC users. Demand

Table 6.1 The short-term applicability of blockchain from the DSO perspective.

DSO&Blockchain Aspects	Shortcomings in Terms of		Applicability in the Short Term	Main Obstacle of Blockchain
	Computational Power	Incentive Mechanism		
SCADA	High	N/A	Medium	Low computational power at end points (sensors, relay devices, circuit breakers) Highly centralized structure
AMI	High	N/A	Medium	Low computational power Low communication power Lack of widespread communication network substructure Scalability
EVs	Low	High	High	Lack of incentive mechanism Privacy concerns Scalability Negative effects on grid, e.g., grid congestion
DERs	Medium	Medium	High	Security concerns
Microgrids	Medium	Medium	Medium	Lack of legal regulation
Marketing	N/A	Low	High	Lack of legal regulation Scalability Speed Security Privacy
Demand Response	N/A	High	High	Lack of legal regulation
DSO/TSO Interaction	N/A	No	Medium	Lack of legal regulation

response may require a highly stimulated structure in the BC. The inadequacy of legal regulation is one of the notable obstacles to the BC transformation.

a) From the SCADA and AMI perspectives, the main obstacle that emerging blockchain technologies face is the deficiency of the computational power of existing devices. The SCADA network is a centralized system, and decentralized blockchain is highly contradictory. AMI has insufficient communication hardware to cope with blockchain necessities, and the number of participants can cause scalability issues. Although SCADA is fast in the current situation, it is weaker in terms of cyber security compared to BC. In AMI, on the other hand, more attention should be paid to privacy issues as it caters more to individual use. In summary, if BC performs better in terms of speed, only then can it be more successful in terms of both AMI and SCADA, secure and private in existing systems.
b) From a blockchain-related EV perspective, the existing structure is insufficient to encourage most EVOs to participate in the BC environment because of the lack of an intensive/reward mechanism.
c) Both DERs and microgrids have a lack of regulatory unity and raise potential security concerns.
d) From the market perspective, transaction time/speed is a significant and non-negligible matter. Regardless of the amount of energy, energy trading occurs every second, and future BC structures must cope with these scalability and speed issues.
e) Apart from cyber-attacks, it is a matter of debate regarding who should be responsible for the physical manipulation or intervention of measurement or control devices. In the event of such physical attacks due to the decentralized nature of the blockchain, it is almost impossible to detect the amount and party of the commercial relation. The difficulty of determining possible fraud also poses new challenges to DSOs. One of the partial solutions can be the use of AI technology to detect possible physical fraudulent attacks from users' previous consumption or production patterns. However, this seems inadequate for the current infrastructure.
f) Unlike cryptocurrencies, transactions in the electricity sector are continuous. In other words, validation of transactions takes time, and with cryptocurrencies, users have to wait until confirmation. However, in the energy sector, energy flow is perpetual, and even if a transaction is not confirmed, real trading will be almost complete and energy delivered to the other party. Therefore, it is unclear what will happen if communication or validation problems occur in the system.

Along with the increase in DERs (connected to the DSO level), bilateral power flow has been increasing gradually in recent years, and this situation forces DSOs to act more like TSOs. In this context, future research should investigate the DSO-level ancillary service–blockchain interaction and its areas of application, particularly regarding the sustainability of the grid in a secure and private manner. All these abovementioned information and the short-term applicability of blockchain from the DSO perspective are listed briefly in Table 5.1.

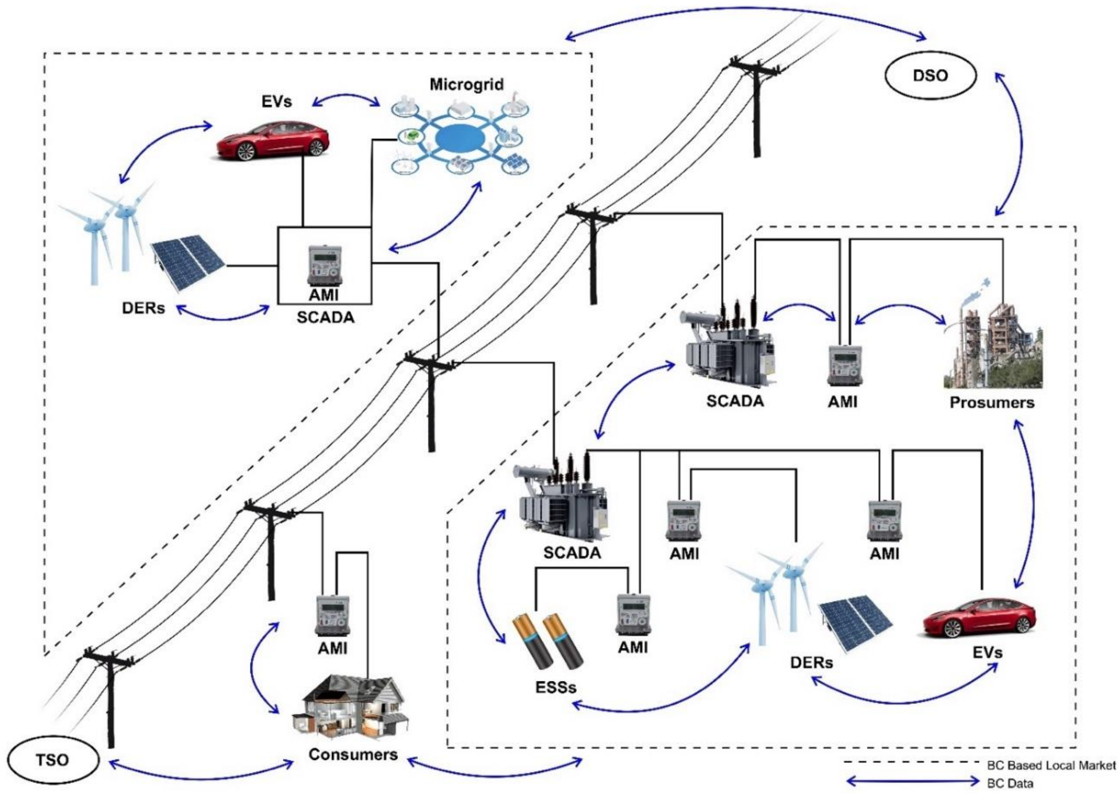

Figure 6.1 DSO grid control unit (SCADA, AMI) connection diagram.

Grid management, grid control, grid monitoring, and customer management are vital responsibilities of the DSO; therefore, the positions of SCADA and AMI are obviously extremely specific. Both SCADA and AMI, particularly AMI, are directly or indirectly connected to all customers/stakeholders electrically, and these DSO grid control units' connection diagram is illustrated in Figure 5.1. Any load change in the grid, even infinitesimal changes, must be measured and controlled by the DSO and responded to as soon as possible. The DSO's technical centrality makes its existence crucial in BC networks, especially in the consumption/production billing of grid usage, registration of new customers in the system, and other grid management procedures. However, the security, privacy, immutability, and accountability attributes of the energy system procured by BC technology, its physical security and security of supply, the technical and commercial quality of the system, improved efficiency of grid operations, reductions in technical losses, and sustainability of the entire energy system must remain under the control of the DSO. These inseparable features of the energy network make the DSO crucial and more important than ever.

6.2 Societal Impact and Contribution to Global Sustainability

Blockchain is one of the promising technology that will probably impact global economy the most, particularly in near future. Even blockchain in finance (De-Fi) is in very early stages of the financial environment, finance is the most mature area of all other blockchain applications. Nevertheless, apart from other usage areas of blockchain, energy will be the second highest attracting attention of the public and the expert. Distributed structure of blockchain is suitable for distributed energy production and consumption form of electricity grid. Due to new user behavior and stronger libertarian opinion, the blockchain will find unalterable place in rapidly changing global economy and energy. As a decentralized data sharing technology, the blockchain will more likely be the revolutionary development of humankind just as the Internet.

Trusting friends and institutions is very common and normal for modern people, however trusting no one but everyone is brand-new idea, and it will be painful for some of us to get used to. However, the strike sparks off people and the new technology, it will take some time, and the harmony will satisfy everyone in the end. Freedom and confidence will attract all people to use it.

Energy is one of the inseparable parts of global economy and smart grid is the main part of the energy sector somehow. The smarter and more self-sufficient the grid grows, the stronger and more sustainable it becomes. The blockchain makes the grid smarter and solves technical problems by itself. Furthermore, the natural development and transition of grid technology has resulted in a grid system that is becoming more decentralized by the year. Blockchain is one of the most promising alternatives to these problems; in terms of achieving SG requirements of DSOs, it will most certainly dominate the entire power system and become an integral part of our everyday electric usage routine.

6.3 Future Prospects

Considering the implications presented in this article, several new questions remain to be resolved. A few of the most prominent are summarized in this section. Despite the transition to a decentralized structure because of BC, the selfmanaged smart BC promises a stronger infrastructure. This BC structure, which is as exible and strict as possible within the framework of its rules, can be turned into a great advantage and can be used in every area in the network. For example, a mechanism, such as ancillary service, which has an important role in energy supply security and electricity technical quality, can be used more efciently and safely because of BC. Ancillary service and similarly VPP should include all energy users in the system and be examined in detail, especially for EVs.

Although BC-based systems (especially in the financial sector) have proven themselves in terms of security, it is not certain what other problems may arise in an area, such as the energy sector where there is a multifaceted and physical instant trade. Considering that the system will run on millions of nodes, this will result in serious security problems, and hence, should be examined comprehensively. Additionally, the increase in the number of nodes will result in scalability and validation speed problems.In chapter 4, the blockchain-based DSM mechanism is analyzed and the total saving that most possibly DSO will have procured. On purpose of determine the cost of applying BC can only be acquired by creating real field pilot projects. Due to the requirements of CA and grid equipments, real field projects must be done to demonstrate and calculate the real cost of applying BC.

The limited adoption of BC technology and the fact that it has not been able to create satisfactory trust in terms of social perception is one of the most important problems in BC. Therefore, it would be benecial to test different scenarios by investigating all kinds of incentive mechanisms so that everyone can adapt to this system. Additionally, with the regulation arrangements, citizens can act more freely. Today, there are BC-based projects that work locally, which this study has attempted to summarize. There are multiple players in the energy sector. However, current projects have not been able to propose a system that includes all energy users. Regulatory arrangements are needed to ensure coordination among all energy users. BC applications in energy should be evaluated as a libertarian field with legislation and its way should be paved. Especially in some countries, the overwhelming power of governments in the energy sector necessitates regulation. Also real experiments needed to achieve the requiremets of proposed system.

6.4 Conclusion

Many studies have discussed the benefits of blockchain applications and the possible negative aspects of the energy sector. In short, it seems that DERs, microgrids, and particularly electric vehicles (EVs) and charging facility units (CFUs) will be emergent actors of the electricity grid, and from the DSOs' perspective, there will be challenges on the grid, such as the short-term peak load management problem and grid capacity concerns due to the quick charging technology and instant energy production changes. However, the security, privacy, scalability, and transaction speed of blockchain technologies in the energy sector are other concerns. Despite blockchain's magnificent, decentralized solutions, the role of DSOs is undeniable because of the existing grid structure. Numerous blockchain-based studies have highlighted EVs, energy markets, distributed energy resources (DERs), microgrids, and demand response (DR) from the perspective of appropriateness. Nevertheless, the applicability of blockchain in the energy system and the considerable need for the current operation of DSOs have mostly not been extensively addressed. Although blockchain has a wonderful problem-solving capacity, the transition from conventional to modern blockchain-based power grids is significantly expensive and difficult to realize in a short time. In the short term, building a completely distributed power system will be nearly impossible, and the transition must be examined in depth. Time series analysis applied to forecast future peak load of the grid in pilot region. Reducing the peak load by using BC based demand side management mechanism scenario evaluated and total saving of grid investment is analyzed. We searched and analyzed the blockchain-based energy sector literature and defined DSO-based requirements for potential blockchain applications in the energy sector.

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CURRICULUM VITAE

2006 – 2010	B.Sc., Electrical and Electronics Engineering, Gazi University, Ankara, TÜRKİYE
2010 – 2011	High Voltage Cables Test Engineer, Hasçelik Cable Kayseri, TÜRKİYE
2011 – 2012	Electricity Disitribution Project Engineer, ÇEDAŞ Sivas, TÜRKİYE
2012 - Present	Smart Meter and Energy Market Expert TÜRKİYE
2019- 2022	MSc., Electrical and Computer Engineering, Abdullah Gül University, Kayseri, TÜRKİYE

SELECTED PUBLICATIONS

J1) A. Yagmur, B. A. Dedeturk, A. Soran, J. Jung and A. Onen, "Blockchain-Based Energy Applications: The DSO Perspective," in IEEE Access, vol. 9, pp. 145605-145625, 2021, doi: 10.1109/ACCESS.2021.3122987. (October 2021)