Review

Blockchain Technology Applied in IoV Demand Response Management: A Systematic Literature Review

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Abstract: Energy management in the Internet of Vehicles (IoV) is becoming more prevalent as the usage of distributed Electric Vehicles (EV) grows. As a result, Demand Response (DR) management has been introduced to achieve efficient energy management in IoV. Through DR management, EV drivers are allowed to adjust their energy consumption and generation based on a variety of parameters, such as cost, driving patterns and driving routes. Nonetheless, research in IoV DR management is still in its early stages, and the implementation of DR schemes faces a number of significant hurdles. Blockchain is used to solve some of them (e.g., incentivization, privacy and security issues, lack of interoperability and high mobility). For instance, blockchain enables the introduction of safe, reliable and decentralized Peer-to-Peer (P2P) energy trading. The combination of blockchain and IoV is a new promising approach to further improve/overcome the aforementioned limitations. However, there is limited literature in Demand Response Management (DRM) schemes designed for IoV. Therefore, there is a need for a systematic literature review (SLR) to collect and critically analyze the existing relevant literature, in an attempt to highlight open issues. Thus, in this article, we conduct a SLR, investigating how blockchain technology assists the area of DRM in IoV. We contribute to the body of knowledge by offering a set of observations and research challenges on blockchain-based DRM in IoV. In doing so, we allow other researchers to focus their work on them, and further contribute to this area.

Keywords: blockchain; smart grid; internet of vehicles; demand response; systematic literature review

1. Introduction

Blockchain was first proposed as Bitcoin's distributed ledger to alleviate the double-spending problem. One of the most important characteristics of blockchain is that, due to its transparency and immutability, it enables participants to establish trust among unknown entities in a decentralized way [1,2]. Recently, in the area of smart mobility, blockchain has risen as an upcoming technology, enabling decentralized mobility services, secure and reliable P2P energy trading between EVs, secure authentication and more [3]. According to Markets and Markets [4], by 2030, the automotive blockchain market is expected to have grown from USD 0.35 billion in 2020 to USD 5.29 billion, drawing the attention of a variety of stakeholders (e.g., investors, business experts, academics and governments).

Additionally, cities are becoming smarter and more connected, due to the rapid advancement of the Internet of Things (IoT). IoT allows connected vehicles (e.g., electric vehicles) to gradually evolve into self-driving vehicles, but none of this will be feasible without a new advanced network [5]. Thus, IoV has emerged as technology that allows vehicle information exchange, efficiency and safety with each other. IoV is powered by smart vehicles, Artificial Intelligence and IoT [6,7]. In the context of IoV, smart vehicles use the Internet to communicate with each other and connect with drivers or passengers, as well as with roadside facilities [8]. The most important communication examples are Vehicle-to-Vehicle (V2V) and Vehicle-to-Grid (V2G) [9].

Yet, the widespread utilization of dispersed EVs creates problems for the energy management in IoV [10,11]. A possible solution is DR management, which might be used in IoV to allow energy consumers (i.e., EV drivers) to adjust their energy consumption patterns based on the cost [12,13]. Specifically, DR allows customers to play an important part in the energy grid operation by decreasing or changing their power usage during peak hours in response to time-based tariffs or other types of financial incentives. Several electric system operators utilize DR programs as alternatives for balancing supply and demand [14]. Such programs can reduce the cost of electricity in energy markets, resulting in reduced market prices. Time-based pricing schemes, including critical peak, variable peak, time of use and real-time pricing, are examples of how market players might participate in demand response [15,16].

Nevertheless, research in the area of IoV DR is still in its early stages and the deployment of IoV DR in smart grids confronts a number of important challenges [17,18]. Specifically, IoV currently lacks sufficient security and privacy procedures to reduce inaccurate and malicious information transfers between EVs [19,20]. There is also a lack of incentive mechanisms to encourage prosumers (i.e., producer and consumer) to join in such DR schemes. EV owners are hesitant to join in large-scale trading networks unless they are highly compensated (i.e., incentivization schemes), due to higher battery drain and other costs associated with discharging [21,22]. Additionally, IoV's characteristics, such as high mobility, low latency, network complexity and heterogeneity, pose substantial issues when typical cloud-based storage and management is incorporated. As a result, to be ready for the future expansion of IoV and fulfill its potential, the data interchange and storage infrastructure may be distributed, decentralized, interoperable, adaptable and scalable [23–26].

From a different point of view, blockchain can be seen as a promising technology in the area of smart mobility and EVs, as it can support secure, reliable and decentralized energy trading [3,27,28]. Blockchain technology provides transparency regarding energy production and consumption. Moreover, blockchain has the potential to give a considerable number of unique solutions in the majority of IoV applications [6]. For that reason, researchers have started developing IoV applications based on blockchain technology [29–31]. IoV built on blockchain has the capacity to boost a new ecosystem for the transportation and vehicular industries, allowing energy assets to be transferred and managed in a secure, transparent, verifiable and efficient manner [32–34].

Despite the fact that IoV is a relatively new technology, it is known that decentralized designs and processes are required to manage energy generation and consumption. Based on our research findings presented in [6], instability in energy production may jeopardize the energy supply security, leading to energy overload and a greatly distributed and continuously changing IoV topology. As a result, we concluded that more study into DR management, which uses blockchain technology to balance energy consumption and supply, was required. In this regard, blockchain appears to have the potential to be an innovative paradigm, addressing limitations in IoV, such as variability in energy production, energy overload and lack of incentive mechanisms [6]. Even though there are several studies that investigate the blockchain technology in the energy domain, there is limited information regarding how blockchain could be incorporated in DR management schemes designed for IoV. Therefore, there is a need to collect and critically analyze the existing literature in an attempt to highlight open issues. Thus, in this article, we conduct a SLR, investigating how blockchain technology assists the area of DRM in IoV. We contribute to the body of knowledge by offering a set of observations and research challenges on blockchain-based DRM in IoV, as the outcome of addressing the following SLR Question: "*How can blockchain technology assist the area of demand response management in IoV-assisted smart grids?*".

To this end, our study makes the following contributions based on a systematic literature review methodology:

1. Collects and filters the available literature, in an attempt to present current perspectives and research efforts on blockchain-enabled DRM in IoV.

2. Critically analyzes and reports the review's outcomes, in an attempt to discuss the various IoV DRM solutions and scenarios and provide a taxonomy of demand response programs.
3. Focuses on the perspectives and research efforts around the demand response management in the IoV, taking into consideration the application of blockchain technology.
4. Provides a comprehensive list of observations and research challenges of blockchain technology in the IoV DRM.

The rest of this article is structured as follows. Section 2 provides a description of the followed research methodology of the current review, describing step by step the three stages of this articles, based on Kitchenham's approach [35,36], as well as features of the PRISMA methodology [37]. Then, Section 3 presents the main findings and the knowledge extracted during the review around current perspectives and research efforts on blockchain-enabled DRM in IoV, while in Section 4, we critically discuss their findings, providing their main observations, as well as some limitations and research gaps. Finally, Section 5 concludes the paper, highlights its contributions and makes recommendations for further research. Lastly, we would like to mention that we provide a detailed list of abbreviations, in an attempt to ease the understanding of the concepts presented in this article.

2. Systematic Literature Review Methodology

The current study was based on Kitchenham's methodology and on [35,36], as well as on features of the PRISMA statement [37]. This review followed the following steps:

1. Plan the review: Determine the rationale of the review, define the research questions and create the review process.
2. Conduct the review: Carry out the established protocol, select studies and assess their quality.
3. Report the review: Presents the review findings.

2.1. Plan the Review

The current review was built on top of the findings of our previous work presented in [6]. In particular, our earlier research indicated that blockchain offers novel opportunities for vehicle owners to engage in the IoV. However, further research is needed into the DRM. Therefore, continuing our work, the detailed description of the SLR methodology and review protocol can be found in that article. Following that, several components of the current review process were directed by the research questions, including setting inclusion and exclusion criteria, searching for relevant studies, gathering data and presenting findings. The current systematic literature review aims to answer the following main question:

> *SLR Question: How can blockchain technology assist the area of demand response management in IoV-assisted smart grids?*

We identified a set of search queries and databases, while planning the review. It is worth noting that the systematic literature search began in 2017 and spanned the previous five years of research innovation and progress. The search database sources were IEEEXplore, SpringerLink, ScienceDirect, ACM Digital Library and Google Scholar. Because this study focused on the scientific knowledge of blockchain adoption in the IoV concept, we emphasized literature published in academic journals, conference proceedings, and book chapters. Then, we defined the SLR's keywords and the queries that were used in the aforementioned databases (Table 1).

2.2. Conduct the Review

We identified 1254 studies that were related to our criteria. We examined for probable duplication inside the union of all databases' responses before continuing on to the screening procedure. After deleting the duplicates, the results for the screening were 1086, as shown in Figure 1. Moving on to the screening procedure, we assessed the suitability and quality of the collected studies using a set of quality criteria for exclusion and inclusion

that we presented in our initial study [6] and present also in Table 2. Then, using those criteria, we looked at the abstracts and keywords of the 1086 papers. During the abstract reading, we concentrated on two qualifying criteria: Is the paper about blockchain? Is there a concept, framework or research in the article that relates to demand response management? To be eligible, papers had to fulfill both requirements. Then, 326 articles were left for review using this method. We continued to evaluate the normative literature after the screening step. We were able to exclude 110 papers because they were unrelated to the review's objective, leaving 106 research to be considered. The approach for identification, screening, and inclusion is depicted in detail in Figure 1.

Table 1. Keywords and search queries for the systematic literature review.

Keyword	Query
blockchain IoV Internet of Vehicles smart grid smart city demand response applications challenges	blockchain AND "demand response" AND (IoV OR "Internet of Vehicles" OR "Smart Grid" OR "Smart City") AND (applications OR challenges)
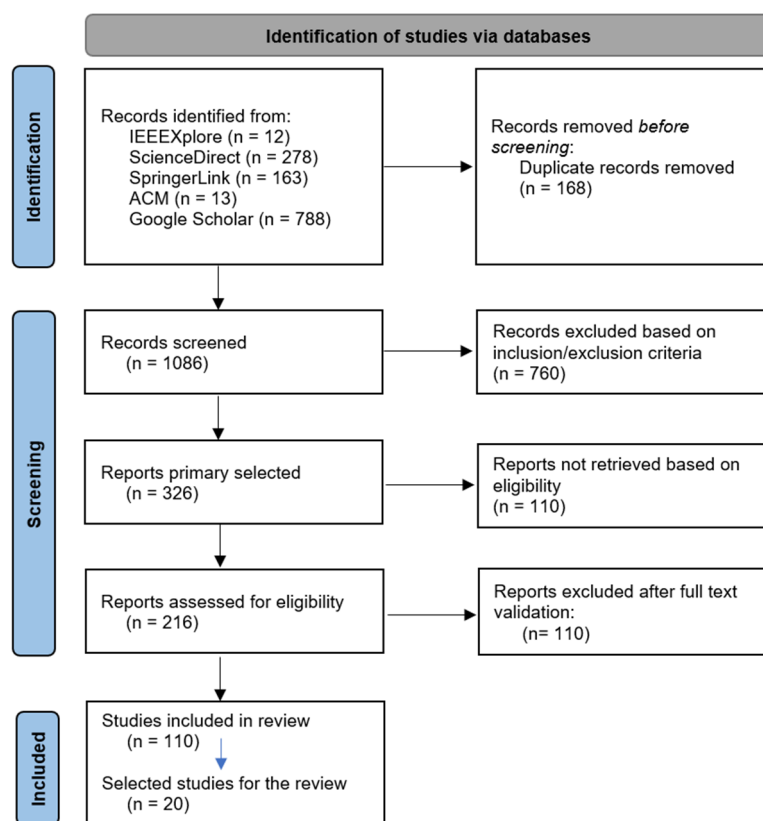
Figure 1. Identification of studies via databases (PRISMA flow diagram).

Following that, the purpose was to use the data extraction to appropriately document the knowledge gathered from the research that were included. The following information was gathered from each study:

- Authors, publication year, paper type, publishing location and digital object identifier were all required fields.
- Evaluation of the study in terms of research knowledge, including the following:

○　The study's issues;
○　The study's results and key findings;
○　The study's limitations and/or research approaches.

A detailed presentation of the research findings and the extracted knowledge is provided in Sections 3 and 4.

Table 2. Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Peer-reviewed studies	Grey literature
Academic theoretical and empirical research	White papers and material from non-academic sources
Full-text available	Full-text not available
Written in the English language	Not written in the English language
Published in 2017 onwards	Published before 2017
Relevant to blockchain and the IoV concept	Diverged from the field of blockchain and the IoV concept
Concept addressed by means of a valid methodology	

2.3. Report the Review

The majority of the studies were journal articles and high-quality conference papers, although some book chapters were also analyzed. A clear depiction of the types of publications identified is presented in Figure 2, while their distribution within the time range of the review is presented in Figure 3. Moreover, their publishers are also presented in Figure 4. From the primary studies (i.e., cluster of 106), the most interesting and relevant ones were selected (excluding the documents in the form of a survey or literature review, which were also considered separately) to highlight the main current research trends and the gaps that have yet to be filled. We selected studies only considering if the paper's argument was built on an appropriate base of theory and concepts, and if the evaluation results were clearly presented and appropriately analyzed. The selected studies were 20 papers and are presented in Appendix A.
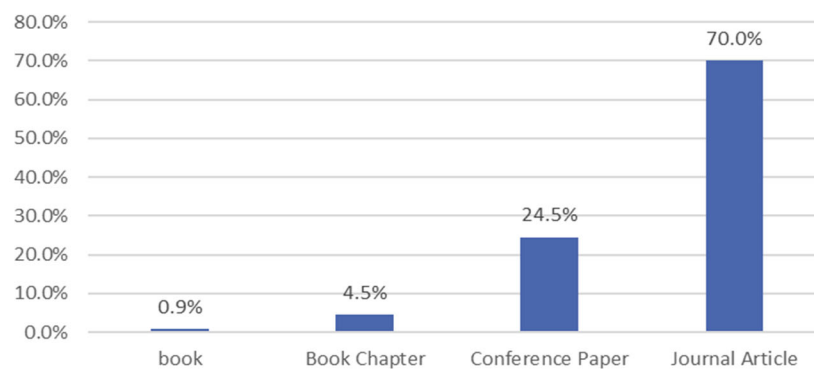
Figure 2. Distribution of the identified studies based on their type.

The following features were highlighted: problem statement, proposed solution/objectives and outcomes/limitations.

Evaluating the selected studies in terms of research knowledge, it appears that current studies partially tackle DRM designed for IoV. There were studies that were separately studied and solved some of the IoV issues, although none succeed in tackling all of them holistically, providing a systematic literature review or focusing on how blockchain could be incorporated into DR management schemes designed for IoV. The aforementioned statement is supported by Table 3, where it can be seen that no work was identified to employ blockchain-based privacy, DRM, V2V/V2G energy trading, charging scheduling,

incentivization schemes and EV profiles. Table 3 summarizes and compares the main features observed in the literature review.
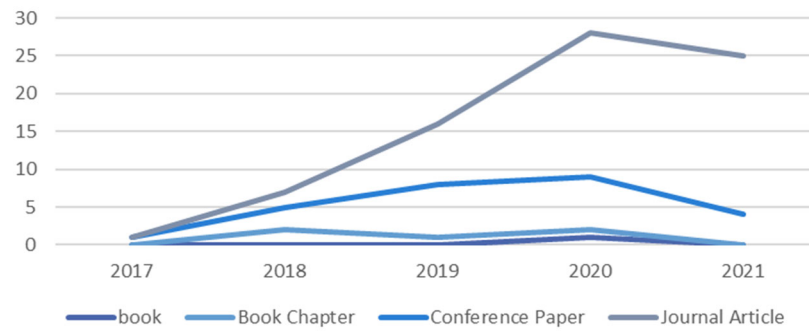

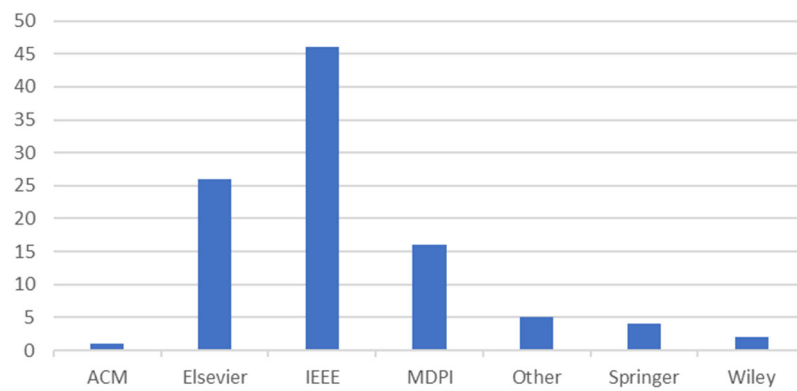**Figure 3.** Distribution of the identified studies within the review's time range.

Figure 4. Publishers for the identified primary studies.

Table 3. Inclusion and exclusion criteria.

Reference (Selected Studies)	Blockchain-Based Privacy	Demand Response Management	V2V/V2G Energy Trading	Charging Scheduling	Incentive Mechanism	EV Profiles
[38]	•		•	•		
[39]	•	•	•			
[40]		•				
[41]		•		•	•	
[42]				•		•
[43]	•		•			
[44]			•			
[45]	•	•	•			
[46]			•	•		
[47]		•			•	
[48]					•	•
[12]	•	•	•			
[49]	•		•	•	•	
[50]					•	
[51]		•			•	•
[52]	•		•			
[53]	•					
[54]	•			•		
[55]		•	•			•
[56]	•	•			•	
This SLR	•	•	•	•	•	•

3. Current Perspectives and Research Efforts on Blockchain-Enabled IoV

This section summarizes the research findings derived from the systematic literature review, focusing on the perspectives and research efforts around the demand response management in the IoV, taking into consideration the application of blockchain technology.

3.1. P2P Trading and Management in Energy Blockchain

There are several studies that propose the use of blockchain technology in P2P energy trading [57]. For instance, in [44], a game-theoretic approach for a demand side management model that incorporates a localized PBFT-CB was proposed. The study incorporated the interaction between sellers and buyers, considering the Stackelberg game and non-cooperative static games. Additionally, Brooklyn microgrid was one of the first applied engineering programs of energy blockchain [58]. The project is based on blockchain P2P energy trading without the intermediation of a third-party energy supplier. The Brooklyn microgrid demonstrates that blockchain may be utilized in real-world P2P energy transactions. Moreover, Q. Duan [59] proposed an optimal scheduling and management smart city scheme, within the safe framework of blockchain. To do so, Q. Duan presented an enhanced directed acyclic graph strategy to increase the security of data transactions inside a smart city, as well as a security layer based on blockchain to prevent cyber hacking. Additionally, the LO3 Energy company introduced an energy supply scheme to the closest neighbors based on P2P trading [60]. Lastly, the current literature dictates future distributed ledger implementations and mechanisms and revealed that blockchain is an important part of P2P energy trading [52,61–63].

3.2. Blockchain-Based Demand Response Programs and Optimization Models

Demand response has been recognized as an important tool for managing supply and demand in electrical grids [64]. When there is an electrical deficit, DR becomes an effective alternative for absorbing the energy gap and managing power utilization [47]. Significant initiatives in blockchain-based demand response programs and optimization models are presented below.

To handle demand response in a V2G context, a P2P energy trading mechanism between EVs and network operators was proposed by S. Aggarwal [39], in an attempt to overcome smart grid imbalances and to control the ever-growing energy demands from EVs. Moreover, Z. Guo [47] presented a blockchain-enabled DR scheme with an incentive pricing model. First, the authors proposed a blockchain-enabled DR framework to promote the secure implementation of DR, while then they also designed a dual-incentive mechanism, based on the Stackelberg game model, to successfully implement blockchain demand response management. Furthermore, in the area of IoV, there are also several studies that address the DR problem and propose optimization solutions. For instance, Z. Zhou [54] proposed a consortium blockchain-enabled secure energy trading framework for EVs with a moderate cost, using a contract theory-based incentive mechanism to incentivize more EVs to participate in DR. The proposed optimization scheme falls into the category of difference of convex programing and is solved by using the iterative convex–concave procedure algorithm. Likewise, T. Zhang [41] incorporated a blockchain-based cryptocurrency component, with which the system can incentivize users with monetary and non-monetary means in a flat-rate manner.

In recent years, the implementation of DR programs in smart grids has drawn a lot of academic attention. A taxonomy of these research endeavors is depicted in Figure 5, which was generated from the outcomes of the current SLR. This categorization is based on the DR procedure's control mechanism, customer motives to lower or move their expectations and the DR decision variable.

DR systems have two types of control mechanisms: centralized and distributed. In the centralized mode, consumers connect directly with the electricity network without engaging with one another. In the distributed mode, user interactions feed the network with information about overall usage [65].
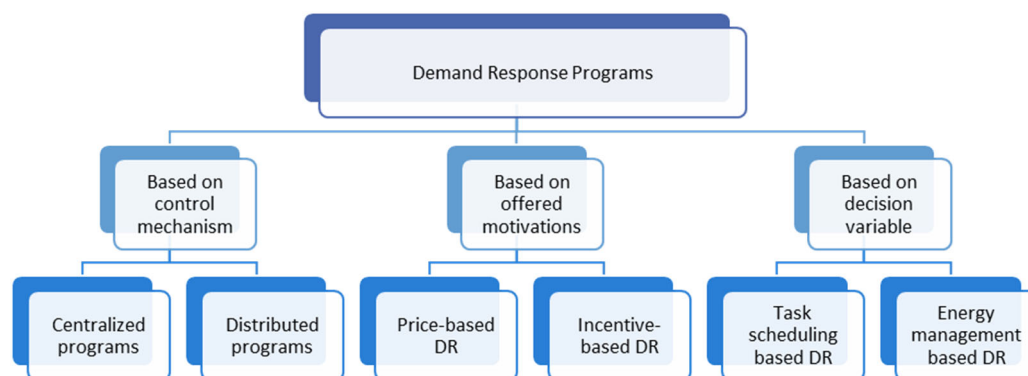
Figure 5. Demand response program taxonomy.

The motivations offered to producers and consumers to decrease their energy usage are classified in the second category of DR schemes. These motivations are divided into two categories:

- Time-based DR: In the time-based DR, consumers are provided time-varying pricing depending on the cost across various time periods.
- Incentive-based DR: Customers in incentive-based DR schemes are offered fixed or time-varying payments to encourage them to reduce their electricity usage during times of system stress [66–68], but they are also subject to specific constraints or are penalized if they do not participate in the program.
- Finally, DR systems that utilize the decision variable to identify task-scheduling and energy-management based DR schemes are classified into the third group [69,70].

The main feature of task scheduling DR is control over the desired load's activation time, which may be moved to peak-demand periods [71,72]. The energy-management-based DR solutions accomplish different power usage during peak-demand hours by decreasing the power consumption of certain loads [73,74].

3.3. Electric Vehicles Charging Scheduling Using Blockchain

To study the consequences of increased EV load and charging mechanisms, the accurate modeling of EV charging profiles is necessary [75]. The size and topology of the energy grid, the number and size of EVs, the mode, time and location of charging as well as the daily driving distance influence the above-mentioned charging profiles. As a consequence, the charging profiles of the drivers are increasingly coupled with charging schedules.

N. Guo et al. [76] proposed a centralized control architecture to handle the modeling and management of EV charging by reducing peak demand and increasing the number of EVs charged concurrently. A common finding in numerous studies on EV battery chargers is that EV battery workloads are commonly thought of as a static, with the actual system behavior of the batteries throughout the charging process being overlooked. In order to tackle the latter, Y. Wu [77] emphasized that a bi-directional energy flow is conceivable. EV batteries may be utilized in the grid in the manner of any other energy storage device, with the additional perk of mobility. The owners of EVs would be able to participate in energy market trading, recharge batteries when energy is cheap and discharge if the smart grid rewards them for their excess energy. This type of energy exchange and negotiation can allow the network to regulate demand (e.g., peak shaving) or offer additional storage in the case of excess renewable energy generation. Consumers will be able to pick where, when and which EV to charge, reducing the strain of the grid.

Using the adaptable EV charging flow, C. Lazaroiu [42] developed a model for smart charging of EVs, in which a software agent selects whether it should load a unit, in what sequence or whether it is better to sell energy to the market. The concept is based on blockchain technology, which makes interactions reliable and traceable, with the goal of decreasing or eliminating intermediaries in energy trade and lowering anxiety.

Furthermore, given the growing popularity of EVs and their unpredictable dynamic nature in terms of charging and route patterns, EV load might be difficult for energy distribution operators and utilities to manage [41]. Thus, T. Zhang proposed SMERCOIN, which is a real-time solution that integrates the concepts of priority and cryptocurrencies to encourage EV owners to charge on a renewable energy-friendly timeframe. Customers with a longer history of utilizing renewable energy are given priority in the system, which uses a rating system. By including cryptocurrency, the system may encourage users using both monetary and non-monetary techniques in a flat-rate manner. Similarly, Z. Zhou [54] developed a distributed, privacy-preserved and incentive-compatible DR mechanism for IoV. In more detail, the authors suggested a low-cost consortium blockchain-enabled secure energy trade platform EVs, as well as an incentive system based on contract theory in order to encourage more EVs to join the DR program.

Furthermore, a dependable solution is required to meet the future energy demands of urban and industrial customers, while also supporting the charging and discharging needs of EVs. Therefore, some research articles have been presented, studying the energy trading in the IoV for demand response management. For example, S. Aggarwal [39] proposed a blockchain-based secure energy trading scheme for demand response management between EVs and the service providers, while a double auction mechanism is proposed between EVs and SPs to maximizes social welfare with privacy preservation. Similar examples can also be found in [12,46], in which the authors analyzed the energy in IoV-assisted smart cities, employing blockchain capabilities in order to select the most suitable charging station without sharing private information, and to balance the spatio-temporal dynamic demands of computing resource.

4. Discussion

The majority of the selected studies mention the need for decentralized DR management in IoV and smart grids, which will primarily promote privacy and security, and then will efficiently incorporate the increasing number of electric vehicles. Likewise, the need for a blockchain framework that offers optimized management and coordination of EV charging is another similarity identified in the literature. The latter is further supported from the common belief that blockchain technology could provide security and privacy of the drivers' data and the exchange of information. In addition, many of the studies highlight that focus should be given to human behavior and preferences, creating EV profiles, which will help the management of the IoV-assisted smart grids and also emphasize different social aspects. Furthermore, another similarity revealed that real-time energy demand is not sufficiently analyzed and explored, considering also the randomness of the EVs events and the unexpected events that may occur during the everyday life.

Finally, the majority of the studies highlight that the advantages of blockchain technology within the IoV-assisted smart grids are numerous, although there is a lack of incentivization schemes that provide relevant rewards to prosumers in order to participate in such schemes. The similarities are depicted in Table 4.

Table 4. Similarities and differences among the selected studies.

Category	Similarities	Differences
Incentivization	Blockchain incentives are needed to encourage participation	Focus on Non-Fungible Tokens (NFTs) as a mean for incentivization scheme
Privacy and Security	Blockchain technology is mostly used for security and privacy	Data analytics scheme for security-aware DRM using blockchain
Demand Response Management	Real-time demand management is not investigated	Incorporate deep learning for intelligent demand response
EV drivers' profile	Drivers' preferences are not considered	n/a
Generic	Consortium blockchain is common in the DRM applications	The proposition is not directly applied in EVs

Furthermore, the SLR reveled some differences (Table 4). The first difference derives from Y.C. Tsao [40], in which the sustainable microgrid design problem is addressed by leveraging blockchain technology to provide real-time-based demand response programs. The study, though, is not coupled with IoV or EVs, although the optimization approach that is proposed is evaluated, making the authors believe that it could be also applied in the area of IoV. Additionally, compared with the rest of the selected studies that are focused on price-based incentives, N. Karandikar [50] focused on non-fungible tokens as a mean for the incentivization of the users. On the contrary, B. Prapadevi [45] reviewed four important themes, such as electric load forecasting, state estimation, energy theft detection and energy sharing and trading, trying to illustrate the need of deep learning solutions in smart grids and demand response. Similarly, A. Kumari [56] reported that current DR management solutions are not adequate in terms of peak loads reduction, consumer comfort and data security issues, and proposed a data analytics scheme for security-aware management. The proposed scheme used blockchain to maintain the grid stability and reduce peak energy consumption.

The discussion presented above led to the following observations, as those are illustrated in Figure 6.
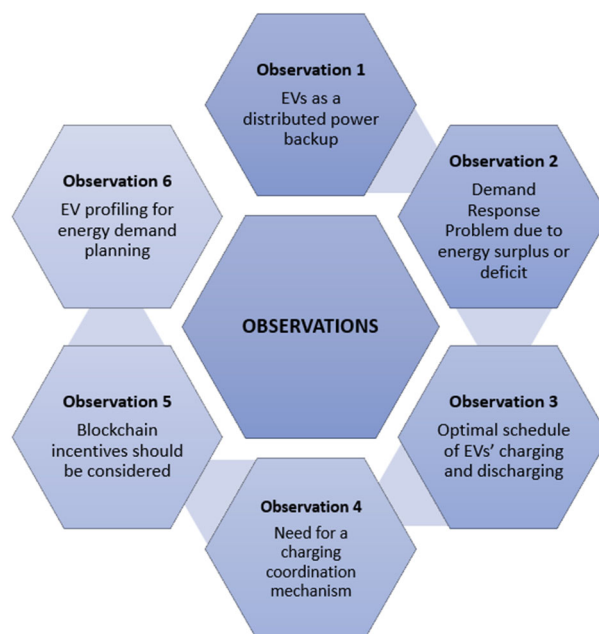
Figure 6. Systematic literature review observations.

Observation 1—EVs as a distributed power backup: EVs can be used as a distributed backup power for the grid, storing electricity during the low period and providing electricity to the power grid during peak period. EVs are not only charged from the grid, but they can also discharge electricity towards that through V2G technology. Hence, EVs may be considered as a distributed backup power, enabling electricity storage during low demand periods, while providing electricity back to the grid during peak periods.

Observation 2—Demand Response Problem due to energy surplus or deficit: Energy surplus or deficit may threaten the security of the energy supply and demand, leading to a demand response problem. The latter is becoming worse considering the randomness of the EV events, which may lead to energy components' overload and culminating with power outages or service disruptions, leading to the so-called demand response problem.

Observation 3—Optimal schedule of EVs' charging and discharging: It is challenging to optimally schedule the charging/discharging behavior of EVs to achieve energy balance, considering the instability of EV demand during specific time periods and/or locations. Specific areas of the IoV-assisted smart grid may increase the demand during

specific time periods and/or locations. Thus, it is a challenge to optimally schedule the charging/discharging behavior of EVs in order to achieve energy balance in the grid.

Observation 4—Need for a charging coordination mechanism: Existing pricing co-ordination techniques have a number of flaws since they rely on a single entity, which might be an untrustworthy third party who is not always truthful when scheduling charging requests. Furthermore, private information about EV owners (such as driving patterns and profiles) could be revealed. To tackle the DR problem in IoV-assisted smart grids, a decentralized, transparent, and privacy-preserving charging coordination mechanism is required.

Observation 5—Blockchain incentives should be considered: Most of the studies consider blockchain technology to ensure the privacy of the EVs, although few of them consider incentive mechanisms to encourage EV drivers to participate in blockchain-enabled DR through optimal scheduling. Existing charging coordination mechanisms suffer from several limitations, e.g., they rely on a single entity, which may be an untrusted party that is not always honest in scheduling charging requests. In most of the selected studies, it was observed that the researchers considered blockchain technology to ensure the privacy of EV owners. However, not many of them considered incentive mechanisms to encourage EV drivers to participate in this kind of blockchain-enabled DR framework. There are a couple of studies, though, that state that the provision of incentives to the participants (e.g., EV drivers, energy providers and households) will be the key to exploit blockchain technology within smart grids and IoV.

Observation 6—EV profiling for energy demand planning: EV profiling should be considered to perform an alignment of EV charging and driver mobility demand towards optimizing electricity demand forecasting and planning. Forecasting the electricity price plays a significant role in reducing energy costs. Moreover, energy demand forecasting helps to maintain the balance between electricity demand and supply in the IoV-assisted smart grid. As a consequence, to achieve the optimization of electricity demand forecasting and planning, EV profiling should be considered.

As discussed in earlier sections, IoV is now under strain as a result of substantial changes in the production and development of EVs. Indeed, the growing malfunctions in power generation need the development of new paradigms. Demand response is an approach in which EV customers actively alter their consumption in response to grid demands. Thus, energy management, which allows the optimal use of constrained energy resources, is required for the establishment of a smart, green and sustainable smart grid. However, the widespread use of unpredictable and uncoordinated EVs creates problems. To balance load and supply, a large number of centralized generators and energy storage devices should be placed, resulting in a considerable CAPEX and operational expense OPEX. Another option is to investigate the rapid spread of DR, which may be used in smart cities to allow energy users to proactively change how and when they use (or create) energy based on the cost (or reward). Because IoV is a participatory data exchange and storage platform, the underlying information exchange system has to be safe, transparent and immutable in order to accomplish the desired objectives. In this regard, the use of blockchain as a system platform for addressing the IoV's demands was investigated. IoV applications enabled by blockchain are thought to offer a variety of desirable features, such as decentralization, security, transparency, immutability and automation, due to their decentralized and immutable nature.

Even though the current studies have several similarities, there are still open research challenges that need to be further investigated. The identified challenges are described below among with some suggestions for further investigation.

Research Challenges and Suggestions 1:

- Research Challenge 1: EV information is exposed, resulting in privacy and security issues.
- Suggestion 1: Blockchain infrastructure and identity management for secure information exchange in IoV.

- Description: The existing charging coordination mechanisms suffer from their relation to a single entity (e.g., the charging coordinator), which can reveal private information about the owners of the EVs (e.g., patterns and drivers' profiles). Thus, the integration of blockchain in the IoV should guarantee the privacy of all participants and the security of the exchanged information.

Research Challenges and Suggestions 2:

- Research Challenge 2: Demand and response in IoV are affected by energy generation and consumption.
- Suggestion 2: V2V/V2G Energy Trading considering EVs' Charging Scheduling addressing the Demand Response Problem.
- Description: The widespread use of unpredictable dispersed RES and uncoordinated EVs creates problems for smart energy management. Current studies are investigating the optimization of the charging scheduling of EVs, although they do not consider the regional energy balance, leading to demand–response gaps and energy imbalances. Thus, emphasis should be given to the energy demand and response of the EVs in specific regions of a smart grid (e.g., considering social events and/or accidents).

Research Challenges and Suggestions 3:

- Research Challenge 3: EV charging profiling from an EV user perspective is not investigated.
- Suggestion 3: EV profiling for optimal charging scheduling and DR balance.
- Description: EV charging profiling from an EV user perspective is not sufficiently investigated. This means that each EV user should be aware of and declare its charging preferences and also to update this information in a continuous manner. In order to successfully control the charging/discharging schedule in comparison to IoV metrics and stability, a certain amount of smartness should be considered.

Research Challenges and Suggestions 4:

- Research Challenge 4: Due to a lack of incentives, EVs with excess energy are not encouraged to act as energy marketers.
- Suggestion 4: Incentive provisioning through rewards and penalties.
- Description: There is too little work conducted in the area of incentivization mechanisms. The majority of the studies do not consider any incentive mechanism to encourage EV drivers to participate in a blockchain-enabled DRM scheme. Therefore, it is necessary to provide an effective incentivization scheme that will give the appropriate rewards and/or penalties to the IoV participants and exploit the blockchain related activities.

5. Conclusions

The current review explores the application of blockchain technology in the rising concept of IoV demand response management, investigating in a systematic way the literature from the beginning of 2017 until the end of and 2021. We satisfied the goals of this review and answered the following research questions: (a) How does blockchain promote the P2P trading among EVs? (b) What is the current status on blockchain-based demand response programs and optimization models and which are the most common techniques for demand response management? and (c) What research work has been conducted regarding EV charging scheduling using blockchain? It is worth mentioning that we extracted knowledge following a systematic methodology based on Kitchenham's approach and present their findings around current perspectives and research efforts on blockchain-enabled IoV DR management. Although we found a vast number of papers using a thorough search procedure, some of them were judged irrelevant. Our findings are categorized in three parts related to: (a) P2P trading and management in energy blockchain, (b) blockchain-based demand response programs and optimization models and (c) electric vehicle charging scheduling using blockchain. Finally, the current study concludes by providing the outcomes of the systematic literature review, highlighting our

main observations and opening research challenges. Additionally, we provided an analysis of the similarities and differences between the reviewed articles, showing, at the end, a set of limitations in the literature. This work goes beyond the currently available studies that focus on the blockchain application in the energy domain in general. Rather than that, the novelty of this study lies in the fact that it provides a systematic literature review in the area of DRM in IoV, based on blockchain technology. Therefore, it provides a thorough analysis of specific parts of the energy domain, emphasizing the above-mentioned perspectives and research efforts on blockchain-enabled IoV.

Our key takeaway from this study is that the disruption of blockchain in IoV is increasing at a fast pace. Currently, there are some studies that tackle the identified research challenges, although none tries to solve them holistically, as it should require a real-world scenario. Thus, we plan to extend the current review to propose more detailed solutions to overcome the identified research challenges. In that sense, we plan to further investigate the need of a unified blockchain framework that tackles all the identified challenges in a holistic way, considering secure energy trading, optimal charging scheduling and motivation towards the demand response management. It is also believed that further research is needed in the area of blockchain-enabled IoV to exploit its full potential and understand the limitations when applied in large-scale deployments.

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Abbreviations

DER	Distributed Energy Recourse
DR	Demand Response
DRM	Demand Response Management
DRP	Demand Response Problem
EV	Electric Vehicle
IoT	Internet of Things
IoV	Internet of Vehicles
ITS	Intelligent Transportation Systems
P2P	Peer to Peer
RES	Renewable Energy Sources
RSU	Road Side Unit
SLR	Systematic Literature Review
V2G	Vehicle-to-Grid
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything

Appendix A

Table A1. Selected Studies.

Title	Problem Description	Study Outcomes/Objectives	Limitations
[38]	Different prices based on demand and response, privacy issues and detection of customers' and EVs' position.	A reliable, automated and privacy-preserving selection of charging stations based on pricing and distance to the electric vehicle.	Possibility of denial-of-service attack. Charging stations are not fully utilized or EVs are not guaranteed a time slot.
[39]	Uncoordinated usage and unregulated energy demand from EVs may increase the demand–supply gap between the service providers and the consumers.	A Peer-to-Peer (P2P) energy trading scheme between EVs and the SPs to manage the demand response in V2G environment, providing incentives to EVs. Consortium blockchain is used to ensure secure energy transactions between EVs and the SPs without a trusted third-party intervention.	Energy scheduling is not considered; Optimal EV charging is not considered
[40]	Sustainable microgrids that simultaneously address economic benefits, environmental and social issues have not been broadly explored by researchers.	Leveraging blockchain technology to provide real-time-based demand response programs.	Blockchain-based smart contracts should be considered in sustainable microgrids to ensure a fair deal for various stakeholders.
[41]	Random dynamic nature of electric vehicle charging and routing cause issues in the electric vehicles' load and could challenge the power distribution operators and utilities.	A real-time system that incorporates the concepts of prioritization and cryptocurrency to incentivize electric vehicle users to collectively charge with a renewable energy-friendly schedule. The study incorporated a blockchain-based cryptocurrency component in order to incentivize users with monetary and non-monetary means in a flat-rate system.	The study was designed based on a photovoltaic generation system and is not evaluated in IoV scenarios.
[42]	The rising demand for electric vehicles will necessitate an increase in charging infrastructures, both to ensure charging system absorption and to disperse energy demand.	A blockchain-based approach for smart charging of electric vehicles, in which a software agent determines whether to load a machine, in what order or whether it is preferable to sell energy to the retail market. The agent adjusts to the individual prosumers of electric vehicles, learning their preferences and mobility habits, so that owners of electric vehicles choose to participate in the system.	Real-time demand is not addressed and blockchain incentives are not clear enough.
[43]	Demand response procedures are transmitted in the smart city with the use of communication infrastructures, which can lead to a variety of attacks in which a malicious user can exploit security flaws in the network.	A safe demand response management system based on blockchain that secures energy trade choices for controlling the total load of domestic, commercial and industrial sectors.	The latency of the proposed system should be decreased and throughput should be increased. Incentives are not present.
[44]	While electricity trading plays an important role in P2P trading, the existing studies have not analyzed the interaction among prosumers regarding pricing.	A game-theory-based pricing model in PBFT-based consortium blockchain is proposed, as well as a rule-based iterative pricing algorithm to obtain the equilibrium prices.	Energy profiles are not taken into consideration neither scheduling algorithms are in place.

Table A1. *Cont.*

Title	Problem Description	Study Outcomes/Objectives	Limitations
[45]	A large amount of data are generated every day in demand response systems from different sources, such as energy production (e.g., wind turbines), transmission and distribution (e.g., microgrids) and load management (e.g., smart meters and electric vehicles).	Analysis of deep learning applications in smart grids and demand response, including electric load forecasting, state estimation, energy theft detection and energy sharing and trading.	Aspects such as dynamic pricing for demand response. load forecasting in smart grids and EV scheduling are not discussed.
[46]	The untrustworthy centralized nature of energy markets and EV charging infrastructures expose EV users' personal information to a number of privacy and security risks.	A blockchain-based charging station selection mechanism for electric vehicles, that ensures EV users' confidentiality and privacy, availability of reserved time slots at the charging stations, Quality of Service (QoS) and improved EV user comfort.	The use of dynamic pricing is restricted. Although it is a vital part in unleashing EVs' flexibility potential, which is necessary for the future grid integration of EVs and renewable energy.
[47]	Demand response necessitates the use of a central agent, which raises security and trust concerns. Furthermore, during incentive pricing, disparities in user response cost features are not considered, affecting the equitable participation of users in DR and increasing expenses.	A blockchain-enabled demand response scheme with an individualized incentive pricing mode is proposed.	More market-realistic scenarios, such as more than one power retail firm engaging in demand response and a higher number of consumers, must be considered. Investigate game and solution models that are appropriate for market-realistic scenarios.
[48]	Increasing available supply to match the projected peak usage value requires the energy operator to over-provision the generation capacity, which can be expensive.	A blockchain-based and data-driven approach for incentive-based peak mitigation.	The study was not implemented in the context of IoV. Additionally, real-time re-scheduling based on unforeseen events was not considered.
[12]	Due to their selfishness and mistrust, smart vehicles with excessive computational power may be hesitant to join in the trading process.	To ensure transaction security and anonymity, a consortium blockchain approach is used. The authors used a consortium blockchain approach to show how to trade safe computing resources and entice individual smart automobiles to join the system. For demand side management, a blockchain-enhanced price incentive demand response is presented. Data verification is recommended to check the validity of the data completed by each user, based on blockchain capabilities, to ensure the credibility of the best energy schedule. All users retain data that are visible, traceable and tamper-proof.	Energy scheduling is not sufficiently analyzed, neither sufficient incentives are provided to participate in the blockchain demand response network.
[49]	Heterogeneous entities on the demand side pose a risk to the power system's reliability and security.		Energy scheduling is not sufficiently analyzed.
[50]	Peak demand times provide a problem to the grid operator since they may need over-provisioning the grid capacity in order to preserve system stability, raising the marginal cost of energy.	Present a unified blockchain-based energy asset transaction system for prosumers, electric cars, power companies and storage providers, incorporating fungible and non-fungible tokens.	Focusing on token incentives, but not on the demand scheduling.

Table A1. *Cont.*

Title	Problem Description	Study Outcomes/Objectives	Limitations
[51]	Because centralized approaches in smart grid management are no longer effective, the necessity for innovative decentralized techniques and designs are generally acknowledged.	A distributed ledger storage and management solution based on blockchain for energy data gathering from IoT and smart metering devices. Self-enforcing smart contracts are also proposed for programmatically specifying the expected energy flexibility at the prosumer level, the related incentives or penalties and the rules for balancing energy demand with energy output at the grid level.	It was pointed that currently the Distributed System Operator is still on control in a centralized manner.
[52]	There are several challenges that consumers and smart grids face when it comes to user's data, including traceability, authorization, data integrity, data security and single point of failure.	The decentralized nature of the local market is highlighted by the usage of a distributed blockchain technology. Through the Periodic Double Auction method, the study provides a decentralized market platform for trading locally without the need for a central middleman.	Decentralized storage is not present.
[53]	Demand response program acceptance is still lacking owing to consumers' lack of understanding, fear of losing control and privacy over their energy data, and other factors.	A decentralized solution for demand response programs on top of a public blockchain that uses zero-knowledge proofs to protect the privacy of the prosumer's energy data and uses smart contracts to validate the prosumer's behavior inside the program on the blockchain.	Smart grid services have varying response time requirements, which affects the accuracy required for energy data monitoring and the costs of integrating an energy blockchain.
[54]	Internet of electric vehicles lacks incentive mechanism and suffers from privacy leakage and security threats.	A blockchain-enabled safe energy trading system for privacy and security in the Internet of vehicles.	Given that the data in a block are encrypted using asymmetric encryption techniques, decrypting them without knowing the secret key is extremely expensive. The computation resources required to determine a block are prohibitive, preventing the widespread adoption of blockchain-based energy trade.
[55]	The extensive deployment of EVs can bring challenges to the grid if not properly integrated.	Propose blockchain-based smart contracts that allow decentralized energy trading among EVs, considering the users' preferences for the charging scheduling models.	Real-time rescheduling of the charging procedure is not considered.
[56]	Increased demand–response gaps and poor service quality of contemporary ICT-based smart grid in industry 4.0 are caused by the exponential rise in energy demand, necessitating the urgent need for an effective Demand Response Management system to address the aforementioned issues. In terms of peak load reduction, customer satisfaction and data security concerns, the available options are insufficient.	A Demand Response Management algorithm is suggested, combined with a customer incentive system, to minimize peak energy usage. The authors propose an Ethereum-based smart contract to address security concerns and the InterPlanetary File System (IPFS) to address data storage costs.	Dynamic pricing strategies, as well as real-time rescheduling concerns, should be explored.

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