Synergies Between Transportation Systems, Energy Hub and the Grid in Smart Cities

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***Abstract*— The concept of smart cities has emerged as an ongoing research in recent years. In this case, there is a proven association between the smart cities and the smart devices, which have caused the power systems to become more flexible, controllable and detectable. Along with these promising results, many disputes have been generated over the cyber-attacks as unpredictable destructive threats, if not properly repelled, which could seriously endanger the power system. With this in mind, this paper explores a novel stochastic virtual assignment (SVA) method based on a directed acyclic graph (DAG) approach, where the essential data of the system sections are broadcasted decentralized through the data blocks, as a worthwhile step to deal with the cyber attacks' risk. To do so, an additional security layer is added to the data blocks aiming to enhance the security of the data against the long lasting data sampling by virtually assigning the hash addresses (HAs) to the data blocks, which are randomly changed based on a stochastic process. The basic network architecture is based on a Provchain structure as a new framework to constantly monitor data operation. Two pivotal strategies also represented to deal with the energy and time needed for the HAs generation process, which have improved the proposed method. In this paper, the proposed security framework is implemented in a smart city environment to provide a secure energy transaction platform. Results show the authenticity of this model and demonstrate the effectiveness of the SVA method in decreasing the successful probability of cyber threat, increasing the time needed for the cyber attacker to decrypt and manipulate the data block.**

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***Index Terms*— Smart city, energy transaction, data security, virtual assignment approach, cyber-attacks.**

NOMENCLATURE

Sets/Indices

Ω^p / p	:	Set/index of subway's stations, $\Omega^p = \{1, \ldots, 6\}$.
Ω^r / r	:	Set/index of urban paths, $\Omega^r = \{1, \ldots, 12\}$.
Ω^t / t	:	Set/index of time, where $\Omega^t = \{1, \ldots, 24\}$.
Ω^e / e	:	Set/index of EV fleets, $\Omega^e = \{1, \ldots, 6\}$.

Constants

α_e^{loss}	:	Loss efficiency of EH energy storage.
$C_{V2G_{e,t}}$, $C_{V2S_{e,t}}$, $C_{p,t}^{SG}$	:	Bidding prices of V2G, V2S, S2V (S2G).
C_e^d	:	The degradation cost of EVs battery.
η_c, η_d	:	Charging and discharging efficiencies, respectively.
η_e^T, η_{boi}^{G2H}, η_{chp}^{G2H}, η_{chp}^{G2E}, η_e^{ch}, η_e^{dch}	:	Efficiency of transformer electricity, the gas to heat conversion of the boiler, gas to heat conversion of the CHP, gas to electricity conversion of the CHP, battery charging and battery discharging, respectively.
$E_e^{\min}/E_e^{\max}$	:	Min/max capacity of the EVs' batteries, respectively.
$Vl_{p,r}$	:	Energy consumption of the EV during traveling through the path k to the station p.
$Vt_{p,r}$	:	Energy supply by the recharging lines through the path k to the station p.
$Load_t^{Grid}$	:	Smart grid demand.
$C_s^{Boi}/C_s^T/C_s^{CHP}/C_s^{Ch}$		Nominal capacity of the boiler/ transformer/ CHP, Boiler and absorption chiller.

$P_e^{ch,\max}/P_e^{ch,\min}$: Min/max charging rate of the EVs' batteries.

$P_e^{dis,\max}/P_e^{dis,\min}$: Min/max discharging rate of the EVs' batteries.

P_t^{eEH}/P_t^{hEH} : Electrical/thermal demands of EH during time t.

$\bar{P}^{Boi}/\bar{P}^{Tr}/\bar{P}^{CHP}$: Nominal capacity of the boiler/ transformer/ CHP.

$\underline{P}^{Batt}/\bar{P}^{Batt}$: Min/max rate of battery charging.

$\underline{P}^{EHUB}$, $\bar{P}^{EHUB}$, $\underline{S}^{Batt}$, $\bar{S}^{Batt}$: Min/max EH input/output power and battery charger level, respectively.

$price_{smart-grid}$: buying/selling price of the energy transaction of the smart grid.

Variables

$cost_{Total}$, $cost_{Hub}$, $cost_{Subway}$, $cost_{EV}$, $cost_{Microgrid}$: Total, Hub, subway's demand supply, EVs and microgrid costs, respectively.

$cost_e^d$: EVs degradation cost.

$cost_{transaction}$, $cost_{Gas}$ Exchanged power between Hub/ smart grid and Gas demand supply costs, repectively.

$cost_{Inv}$ Investment cost of EH elements.

$OF_{Microgrid}$: Total cost of microgrid.

$E_{e,t}^{V2G}$, $E_{e,t}^{V2S}$, $E_{e,t}^{V}$: EV battery capacity during V2G, V2S and total energy transactions, respectively.

I_t^{chBatt}, $I_t^{dchBatt}$: Binary variables of charging and discharging modes of EH energy storage.

$L_{p,t}^{newsubway}$, $nL_{p,t}^{subway}$: Subway's demand after and before changing the based profile.

f_V, f_{V2G}, f_{V2S}, f_{S2G}, f_{SG}, f_{S2V} : EVs, V2G, V2S, S2G, SG and S2V energy transactions profits.

$P_{e,t}^{V2G}$, $P_{e,t}^{V2S}$: V2G and V2S energy transactions, respectively.

$P_{p,r,e,t}^{V2S\_c}/P_{p,r,e,t}^{V2S\_d}$: Charging/discharging power during V2S, respectively.

$P_{r,e,t}^{V2G\_c}/P_{r,e,t}^{V2G\_d}$: Charging/discharging power during V2G, respectively.

$E_{e,t}^{V}$, $P_{e,t}^{V\_c}$, $P_{e,t}^{V\_d}$: Energy exchange of the EVs, charging and discharging power of the EVs, respectively.

$P_{p,t}^{S2G}$, $P_{p,t}^{G2S}$: S2G and G2S energy transactions, respectively.

$P_{p,t}^{BE}$: Subway maximum braking energy.

P^{Grid} : Power transaction of smart grid

$P_t^{Microgrid}$: Total output power of the proposed microgrid.

P_t^{EHUB} : EH exchanged power to the grid during time slot t.

P_t^{GasIN} : EH gas input power during time slot t.

$P_t^{Gas_{chp}}$, $P_t^{Gas_{boi}}$: CHP and boiler input gas power at time t, respectively.

$P_t^{chBatt}/P_t^{dchBatt}$: Charging/discharging power of battery within Hub system at time t.

$P_t^{PV}/P_t^{WT}/P_t^{bat}$: output generated powers of PV, WT, battery units.

S_t^{Batt} : The EH battery remaining energy during time slot t.

$u_{p,r,e,t}^{ch}$, $u_{p,r,e,t}^{dis}u_{r,e,t}^{ch}$, $u_{r,e,t}^{dis}$, $ur_{p,r,e,t}$, $ug_{r,e,t}$: Binary variables related to the charging, discharging of the EVs.

P_t^{cbat}, P_t^{dbat} : charging/discharging power of battery within microgrid.

$z_{p,r,e,t}$: Binary variable related to the urban paths.

I. Introduction

A. Motivation and Aims

TODAY cities are concerned with great challenges pertaining to population growth, greenhouse gas emission, clean energy availability and conservation, and economic development, and other factors which make large cities more sustainable and secure [1]. The use of affordable and readily available wireless communication devices allows smart cities to coordinate the delivery of urban services including energy, fuel, transportation, water, and waste water in order to enhance the performances of such cities in extreme conditions [2]. The concept of smart city is developed based on the interconnectivity of system of systems, wherein the information and communication technologies take the center stage [3]. Smart city classifications are considered in [4], [5] in which energy is featured based on various types of smart grid devices encompassing energy storages (ESs) and DERs.

B. Literature Review

A major contributor which makes the establishment of smart cities rather challenging is the notion of customer participation in managing energy demands. Similar challenges are encountered in renewable energy, transportation system, and alike [6]. The two major aspects of customer participation in smart cities include transportation (electric vehicles (EVs) and traffic management) and smart homes. Such new technologies are intended to reduce electricity peaks and reduce greenhouse emissions. The implementation of such technologies is further complicated by uncertainties associated with weather related events such as errors in forecasting solar and wind energies.

C. Smart city

The increasing and escalating demand of the cities has took the center stage during the last few decades. Among all the options and ideas, providing an effective synergy mechanism can be a perfect idea to satisfy the challenges related to the fast growing load demands. Prior to introducing such promising platform, different sections of the smart city, generally including the transportation systems, energy hub, smart grid, need to be properly represented and exploited.

1) Smart Grid: Development of smart devices and communication platforms have been a great step towards the emergence of the concept of smart grids. The communication platforms interlinks different equipment of the electrical grid, which in turn, many achievements are emerged with such technology including the improvement of the operation of the grid as well as the reliability and resiliency of the network [35]. The smart concept of the grids provides the chance of interconnecting the smart grid with other sections of the smart city such as transportation and EH systems, aiming to attain a more efficient energy management procedure.

2) Transportation Systems : With the advent of Vehicle-to-Grid (V2G) as a cutting-edge technology, it becomes possible to inject the stored energy in EVs to the grid for enhancing the power grid operation and control [7]-[9]. In [10], the authors addressed the stochastic V2G performance by engaging aggregators as EVs are considered as demand (charging mode) and mobile storage sources (discharging mode) in power system operation. In [11], uncertainties associated with utilizing EVs and wind turbines (WTs) were investigated considering V2G mode of operation.

A comprehensive research is provided in [12], in which the authors have tried to address the technologies and strategies of minimizing the huge amount of urban railways' energy consumption. A large number of train stations are the inseparable parts of today's smart cities. One reason which may intensify their advantages is the potential of their regenerative braking which is possible to be saved urban railway systems or even the city [13]. Authors in [14] have pointed out that the regenerative braking is an effective method to use the energy of the trains through the traction motors while the trains reducing their speeds. To enhance the effectiveness of such braking energy, the concept of schedules, power storage and reversible stations have also been investigated. Setting a proper schedule on the arrival and departure times of two non-directional trains in order to enhance the usage of their regenerated energy is the aim of [15]. They have also represented an approach for accelerating trains to use the regenerative braking energy with no energy storage units. The authors in [16] have stated that the energy storage unit to capture the regenerating energy will outweigh the complicated synchronization scheduling of the trains. However, one major shortcoming of such method is the cost of energy storage devices which needs to be properly handled. The concept of reversible trains is represented in [17] to capture the braking energy (BE) of the trains by using reversible substations.

3) Energy Hub: Increasing trend of the need for different forms of energy as well as the energy growth in smart cities are the convincing evidences of the advent of multi-carrier energy systems so-called energy hub (EH). Such innovation gathers thermal, electrical and gas infrastructures for commercial, residential and industrial usages. It also includes several inputs and outputs with effective conversion systems to support various kinds of demands in today's energy grids [18]. The utilization of such systems would be a great idea considering energy and environmental issues in smart cities [19]. For the last few years, the communication systems and demands for different types of energy (electrical, thermal, gas and water), have been a great justification for the researchers to propose effective solutions to prevail such challenges [20]. In [21], the authors have investigated the operation of a smart EH in the smart grid based on a smart platform for the system aiming to minimize the operation cost of the smart EH. The operation of a residential EH in the smart grid has been focused in [22], and the systems are interconnected through smart devices. The security of such communication platform and data transaction must be guaranteed against the cyber-attacks which is provided in the next part.

4) Synergy Mechanism: Some investigations have put the spot light on the synergy mechanisms between different segments of smart city to improve the system performance. Authors in [23] pursued the integration of renewable and clean energy sources aiming to supply the demand of an island by means of using a synergy platform. Same approach investigated in [24], however, the authors preferred to improve the flexibility of the system by representing a synergy framework in multi-carrier energy systems considering the uncertainty of the units. Reference [17] concentrated on proving an effective synergy mechanism within the smart transportation system between electric vehicles and trains. In order to benefit from the proper operation of the EVs, reference [25] tried to provide a synergy framework by integrating renewable energy sources and EVs into the distribution system.

5) Security Framework: As it was mentioned before, securing the data transmissions within the smart environment is undeniable. In this regard, many works have been dedicated to investigate a decentralized based data security framework over the last few years so called "blockchain". Generally, the blockchain technology is determined by three different infrastructures including: 1) Decentralized network, 2) Distributed consensus and 3) Cryptographically secure algorithm. The decentralized network is basically about to guarantee that the data blocks are transmitted among the nodes which are formed in a decentralized structure [26]. Distributed consensus, which is a major part of the blockchain platform, is defined based on a series of security protocols which need to be obeyed in the blockchain process. The cryptographically secure algorithm is another essential part of the blockchain. Basically, the data blocks are secured through specific cryptographic-based algorithms, where each one has its own features and procedures [26].

This paper mainly focused on providing a new cryptographic-based securing algorithm which falls into the third category. The blockchain technology is a proper cryptographic based method which can be used to enhance the security of data transactions safely in the smart city. Authors

TABLE I
BRIEF COMPARISON BETWEEN REFERENCES

Reference	Synergy mechanisms			
	Smart Transportation	EH	Smart Grid	Security Framework
[23]	×	×	✓	×
[24]	×	✓	✓	×
[25]	✓	×	✓	×
[17]	✓	×	✓	×
[26]	×	×	×	✓
[30]	×	×	✓	✓
[29]	×	×	✓	✓
Proposed Model	✓	✓	✓	✓

in [27] have tried to investigate blockchain technology with the aim of bringing reliable, decentralized and sustainable industries. Accordingly, in [28], the concept of blockchain technology has been used in microgrids with the aim of fraud prevention and decreasing operating costs [28]. In order to give an exact figure over the use of blockchain technology in the smart grid, authors in [29] provided a proper review on structure, techniques and how to implement such technology. The blockchain technology can be categorized in three different forms including public, consortium and private blockchain [30]. Also, the authors mentioned that the public blockchain has almost 51% of attack possibility, while the other two frameworks have nearly 33.33%. In addition to the blockchain platform, authors in [31] have represented the cybersecurity of energy trading within microgrids relying on directed acyclic graph (DAG) approach. Aiming to assess different aspects of the work, Table I is provided which gives a clear overview on the ideas of relevant references and highlights the differences. All the references and their pros and cons have been analyzed in the literature review section so far. One can conclude that the current work provides a new simultaneous synergy mechanism between different segments of smart city including smart grid, smart transportation system and the EH, secured by a blockchain-based new cryptographic algorithm.

D. Motivation and Aims

The main shortcoming of the conventional blockchain is that an unauthorized access is able to encode the hash address (HA) assignment process for data blocks and get access to the system by long lasting data sampling. The HA function utilized in conventional blockchain and DAG approach as data security platforms which are investigated in references [26] and [29]-[30] are vulnerable against cyber-attacks specially in cases with high amount of communication links i.e. smart city due to their constant and unique HA assignment process. In this regard, an effective and applicable platform for the smart city environment is need to be provided to make the access and fraud hard and unconceivable for the attacker from the perspectives of technical issues, economic and time. To overcome this drawback, this paper has tried to provide a novel stochastic virtual assignment approach (SVA) method to enhance the security of data transaction. The SVA approach basically alters and virtualizes the HAs in a stochastic manner to stop the attackers from getting accessed to the system by eavesdropping and long-lasting data tracking. Such method is applicable and implementable in the environments with vast number of data exchanges. Also, for saving energy and time of the HA generation process, two strategies are represented which can surmount the weaknesses of the proposed method. Such method can also be used for enhancing the security of the energy transactions among different sections of the smart cities.

The primary attributes and characteristics of this work with regard to prior works in the area can be stated as follows:

1) A novel SVA method based on the DAG approach is proposed to enhance the security of data transactions. This approach is highly effective in the environments with vast number of data transactions and high possibility of data attacks that could be vulnerable against data frauds, which makes it extremely hard to tamper the data. Hence, this approach is implemented in the smart city environment to provide a secure energy transaction scheme.
2) This paper introduces an effective synergy mechanism among different sections of the smart city including smart grid, microgrid, smart transportation system and the EH aiming to enhance the efficiency of the smart city.
3) The basic network architecture is based on a Provchain structure as a new framework to constantly monitor data operation.

The remaining sections of the paper are as follows. Section II refers to the SVA approach definition. Section III represents the studied energy transaction within the smart city. Results are provided in section IV and the work is concluded in section V.

II. STOCHASTIC VIRTUAL ASSIGNMENT APPROACH (SVA)

Among recent developments over the concept of "smartness", a secure data transaction still play a key role. Within modern power systems, increasing the reliability of the energy transaction is definitely linked to increasing the level of data security. Such justification surely comes down to vastly cyber attacks' tendency which needs to be hampered. A remarkable progress in doing this has been carried out by blockchain technology, provoked much attention recently. In the following, such secure framework along with the SVM approach is comprehensively defined.

A. Blockchain Technology: A Brief Discussion

In contrary to the supervisory control and data acquisition (SCADA) system, some researchers affirmed that it would be well worth if each node of the system (producers or demands) broadcast the data to the other nodes, decentralized, if it is to be used as a secure and preventive environment against suspicious stealthy accesses. In this regard, the important information of the nodes are broadcasted through the data blocks, each one encrypted by a HA. Each node of the system will create its own data block signed by a private key and then broadcast the data block to the rest of the nodes. The nodes of the system are capable of accessing the data blocks by a

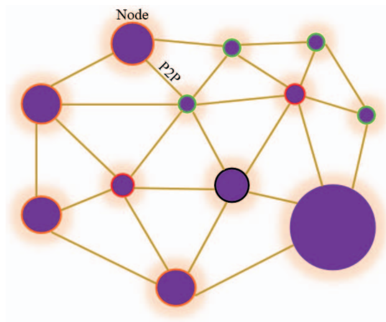


Fig. 1. Blockchain architecture.

public key. Each data block is chained to the previous one results in the formation of the chain of data blocks. Fig. 1, illustrates the architecture of blockchain as an instance. This procedure, however, brings two challenges. The first one is the deterioration of the accuracy of calculating the HAs within a system with a high number of nodes. The second one is the high risk of unaccredited access due to the cyclic form of the data blocks' transactions [32].

B. DAG Approach: Pros and Cons

The disputes over such procedure have led some researchers to propose the directed acyclic graph (DAG) approach. In this approach, the private, public and transaction data of the systems' nodes are generated and broadcasted, separately, through the *private blockchain, public blockchain* and *transaction blockchain*, respectively. Within the private blockchain, the detail information of the nodes of an agent are broadcasted to the other nodes merely belonged to that agent, in such a way that those information will not be received by a second agent of the system. All the agents of the system are capable of access to the public information of each agent through the public blockchain. Each agent will hourly broadcast its transaction information performed within each hour. Such acyclic, decentralized and segregated procedure has decreased the risk of data attacks. However, the possibility of data attacks particularly through the transaction blockchain is still a matter of debate. Due to the interdependency of the HAs between the successive data blocks, an intermediate maliciously unauthorized access might have the chance to receive, monitor or even inject the bad data by data sampling within a certain time period. With this in mind, this paper proposes a novel approach aiming to create a secure circumstance in which the data blocks are transmitted to the receiver preserved against the data attackers [31].

C. Data Block Structure: Blockchain Versus SVA

In the SVA approach, an additional security layer is added to the data blocks which increases the security level of data transmission.

The data blocks are sealed with a label by the transmitter which can be an integer number. Each one of the block labels represents a unique hash generation mechanism which differs from the other labels and each one is used for each data transaction (see Fig. 2) [34]. The selection of the labels for data blocks is a random process merely transparent between the sender and receiver. Such instruction is general for all the system's agents which can be contracted among them before the daily energy transactions.

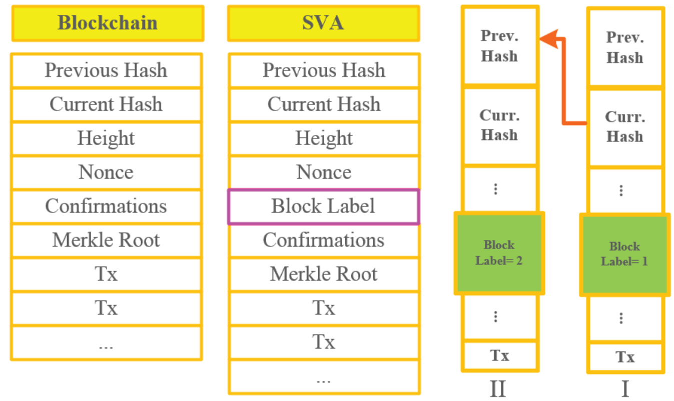


Fig. 2. Structure of the data blocks.

D. Definition of SVA Approach

As previously mentioned, the smart city comprises of different sections, each one inclines to have energy and data transactions with others aiming to satisfy its own objective functions in a more beneficial and logical manner. In this regard, it is expected to have vast number of data exchanges in the smart city environment. One can conclude that a simple data frustration by a stealth malicious access could potentially affect the entire smart city sections and devastate their performances. Looking over such threats and the main features of the smart city, it can be said that the conventional HA functions would be no longer applicable and a new HA function is needed which is advantageous to be used in the smart city environment. This section is intended to define a new HA function for enhancing the security framework in the smart city.

As mentioned earlier, in this paper, the data transmission, storage and validation are implemented on ProvChain structure. ProvChain architecture is a secure cloud data provenance structure which benefits from the blockchain technology to enhance the privacy and security of data records [26]. In this regard, the data provenance utilizing cloud environment will make the data packs more trackable, observable and debuggable. Illustrative representation of the ProvChain is shown in Fig. 3. Considering the proposed structure, all the users' operations can be recorded for provenance data generation. These provenance data are published in the blockchain and can be verified by the nodes of the blockchain network without even knowing whom the data block belong to. Only the provenance auditor (PA) is able to validate the authenticity of data blocks, which are added to the blockchain, by using blockchain receipt [26]. The validation of data blocks by the PA will be discussed in the following. Prior to that, the SVA mechanism needs to be well explained.

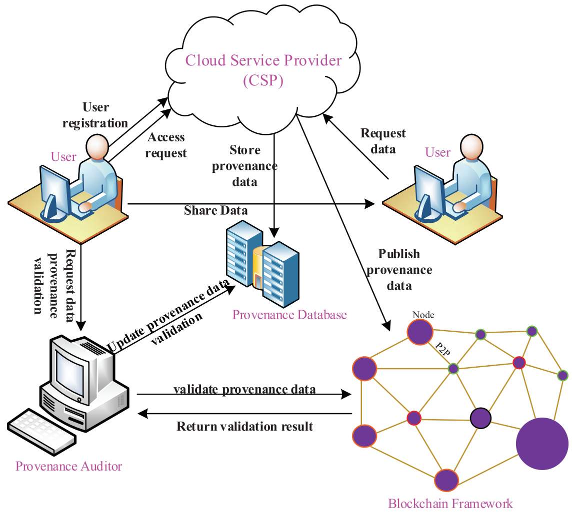


Fig. 3. Structure of the data blocks.

```
Begin:

Validate (proof, merkleRoot, targetHA, block label)
ƛ = Σ_{i∈N} i ; ℑ ="targetHA"; ℵ = block label; κ = 0;

for κ =1: ƛ
    if (proof.d ( κ ) = "right")
        ℑ =hash (SHAx, ( ℑ + proof.v ( κ )));
    else if (proof.d ( κ ) = "left"))
        ℑ =hash (SHAx, (proof.v ( κ ) + ℑ ));
    end
end
if ℑ = "merkleRoot"
    fprintf ('True')
else
    fprintf ('False')
end

END
```

Fig. 4. Pseudo code of provenance data validation considering SVA.

As mentioned before, the *block label* is embedded into the data block which could be an integer number, indicates a unique hash function. For security reasons, each generated data block holds a different *block label* which is randomly selected by the roulette wheel process. On the other hand, each one of the labels expresses an exclusive hash generator explicated for the receiver before. By receiving the data blocks, the receiver is able to have an access to the information of the data block. Focusing on the data transaction between two nodes of the system, such received data are inherently virtual from the perspective of both the sender and receiver, but real from the perspective of a third party.

Hence, another step is needed to be executed on the data block. In this regard, the receiver will exert the source encryption mechanism associated with the block label of the data block (same as the one used by the sender) on the current HA and the merkle root aiming to decode the data and access to the real data. Such process results in two values, equality of which demonstrates the validity and confirmation of the data block. If such comparison leads to the inequality, all the agents will be informed of the data attack instantaneously.

Hence, a meager change in data or the HAs is noticed by the receiver. It is worth mentioning that utilizing such procedure prevents any third party from manipulating the data transacted between two nodes of the network.

In general, the data provenance records are published in the form of data blocks to the blockchain which are then shared among the nodes of the network to verify the proposed data blocks. The verified data blocks which are anchored to the blockchain can be validated by the PA using the block receipt. The formation of data block by the sender (an arbitrary node of the network) as well as the proposed validation procedure by the PA considering the SVA approach is provided in the following.

E. Provenance Data Validation

As it was mentioned before, the provenance data will be published to the blockchain by the cloud service provider (CSP) as data records of the users, which is preceded by storing the data into the provenance database. Validation of the provenance data is carried out by the PA through the blockchain receipt. The blockchain receipt encompasses information including the proof which is basically constructed to validate the transaction, targetHA, merkle root, etc [26].

Fig. 4, depicts the pseudo code for provenance data validation. As can be seen, the process starts with validation of proof, merkleRoot, targetHA and block label in terms of number of digits and other mathematical features. In the algorithm, i indicates the nodes of merkleRoot, N is the set of merkleRoot nodes, $\Im$ is the targetHA, $\aleph$ defines the block label and κ is an arbitrary variable, roles as a counter in the process. Through an iterative process and using the information of the block receipt, the merkle tree can be retrieved and the data records are valid if the constructed merkle tree is equal to the targetHA. It is worth mentioning that the term *proof.d* indicates the direction of the values in merkle tree, since each value in the merkle tree could be right-handed or left-handed as defined in [34].

Also, the term *SHAx* expresses the particular hash function related to the block label. In this regard, x could get values 1, 224, 256, etc [32], [33], depending on which one the sender used in the first place. Finally, if the constructed merkle tree is equal to the target hash, the data records are valid and *True* will be returned in the output.

F. Data Block Formation

This subsection is intended to explain the process of generating a data block. Assume a power network in which the nodes of the system (agents) try to have energy transactions and details are defined in a day-ahead electricity market within 24-hour daily horizon. In this regard, each agent must share its hourly transactions with all the nodes of the system, every time by a different block label. The uniqueness of each HA generation mechanism for each transaction dictates that 24 different HA encryption mechanisms (e.g. $i = 1, 2, \ldots, 24$) being considered for day-ahead hourly energy transactions.

TABLE II
WEIGHTING FACTOR AND HASH FUNCTION ASSIGNMENT

	Generation Function	Block Label	High Distance	Medium Distance	Low Distance
W_1	SHA-512[32]	1	✓	×	×
W_2	SHA-384[32]	2	✓	✓	×
W_3	SHA-256[32]	3	×	✓	×
W_4	SHA-224[33]	4	×	✓	✓
W_5	SHA-1[32]	5	×	×	✓

This might become an energy and time consuming process. To overcome this challenge. Two strategies can be handled to overcome such challenge represented in the following.

G. Strategy I

In this strategy, the number of the HA generation functions is reduced to a certain number depending on the number of active agents of the system. Assume that i denotes the number of HA generation functions. In this strategy, i is reduced to a certain number m in such a way that $i > m$. For the day-ahead energy transactions, m assumed to be 12. The HA generation functions for the first 12-hour transactions are selected among the proposed 12 different HA generation functions. Among these 12 different HA generation functions, each one is randomly selected and replicated for the second 12-hour transactions throughout the day. This will reduce the time and energy needed to generate a different HA for each hour.

H. Strategy II

Here, different HA functions are selected for the data transaction based on the length of the data transmission. To do so, five HA functions in terms of the length of generated HA are chosen as shown in Table II. In this strategy, the data blocks will be signed by different selected HAs considering the length between the source and receiver. Table II shows the HA functions for different lengths. Such HA generation functions can be identified by five weighting factors including W_1 to W_5 and each block is labeled with an integer number from 1 to 5. Different weighting factors are assigned to the HA functions. In this regard, high distances between the sender and receiver need more accurate and secure HA function which is more reliable if it is to be securely guaranteed against unauthorized accesses. Table II shows that the SH functions SHA-512 and SHA-384 are utilized for high distances. For medium distances the hash functions SHA-384, SHA-256, SHA-224 would be effective options. For low distances, the HA functions SHA-224 and SHA-1 are selected. In this regard, a specific weighting factor is assigned to each data block by means of indicating the distance length and also the HA function generator. Fig. 5 depicts the *strategy II*. Fig. 6 illustrates a simple example for implementing the SVA approach between EVs.

This figure shows different EVs which are located apart in three different distances including low, medium and high. If the EVs are located in high distance, HA functions W1 and W2 will be assigned to their data blocks. Also, for the EVs located in medium and low distances, W2-W4 and

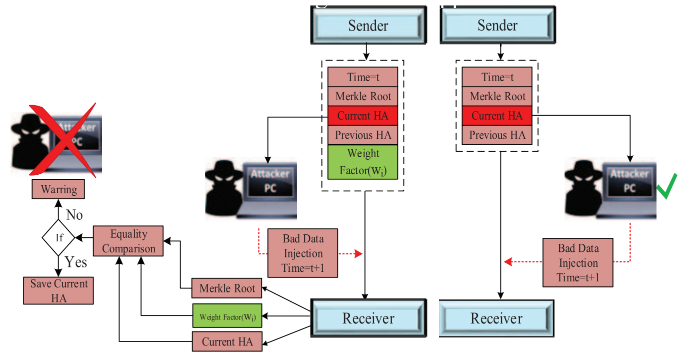


Fig. 5. Data transaction process in strategy II.

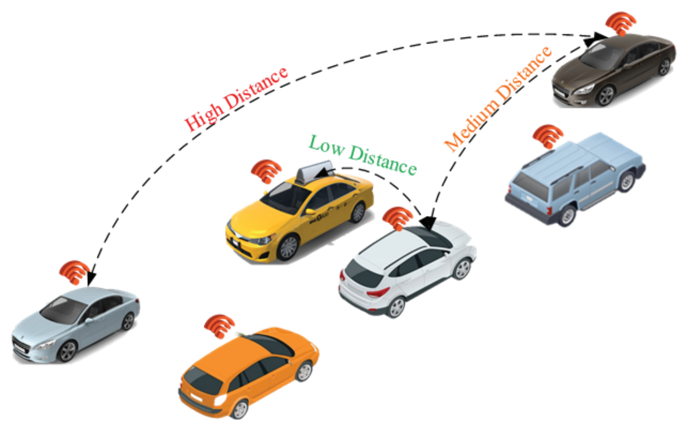


Fig. 6. An example of implementing the SAV on EVs.

W4-W5 will be considered to generate their data blocks, respectively.

Similar to the strategy I, the receiver will assess the validation of the received data block by exerting the weighing factor and its related HA function on the current HA and merkle root. With this method, the HA function generator (generated bits of HA) will no longer be the same for each data transaction and is chosen considering the length of the receiver aiming to save the time and energy needed to generate the HAs. Based on the above explanations, Fig. 7 summarizes the performance of the SVA method in the smart city environment.

I. Time Analysis

Apart from the steps to generate the data block, the time analysis of the process is ineluctable. Assuming a node receives a number of transactions, average of which is ω and intends to prepare a data block encompasses the transactions and sends to the receiver (s). In this regard, the processing time of the blockchain structure can be defined as follows:

$$T_{tot-chain} = \omega \times T_{sig} + (T_{back-off} + T_{trm}) \times 2 + t_{prod} + t_{Mining} \quad (1)$$

where in the above equation, T_{sig} shows the time takes to verify the signature, $T_{back-off}$ is the back-off time which depends on the utilized protocol [26], T_{trm} indicates the transmission time of the data to the receiver, t_{prod} is the time

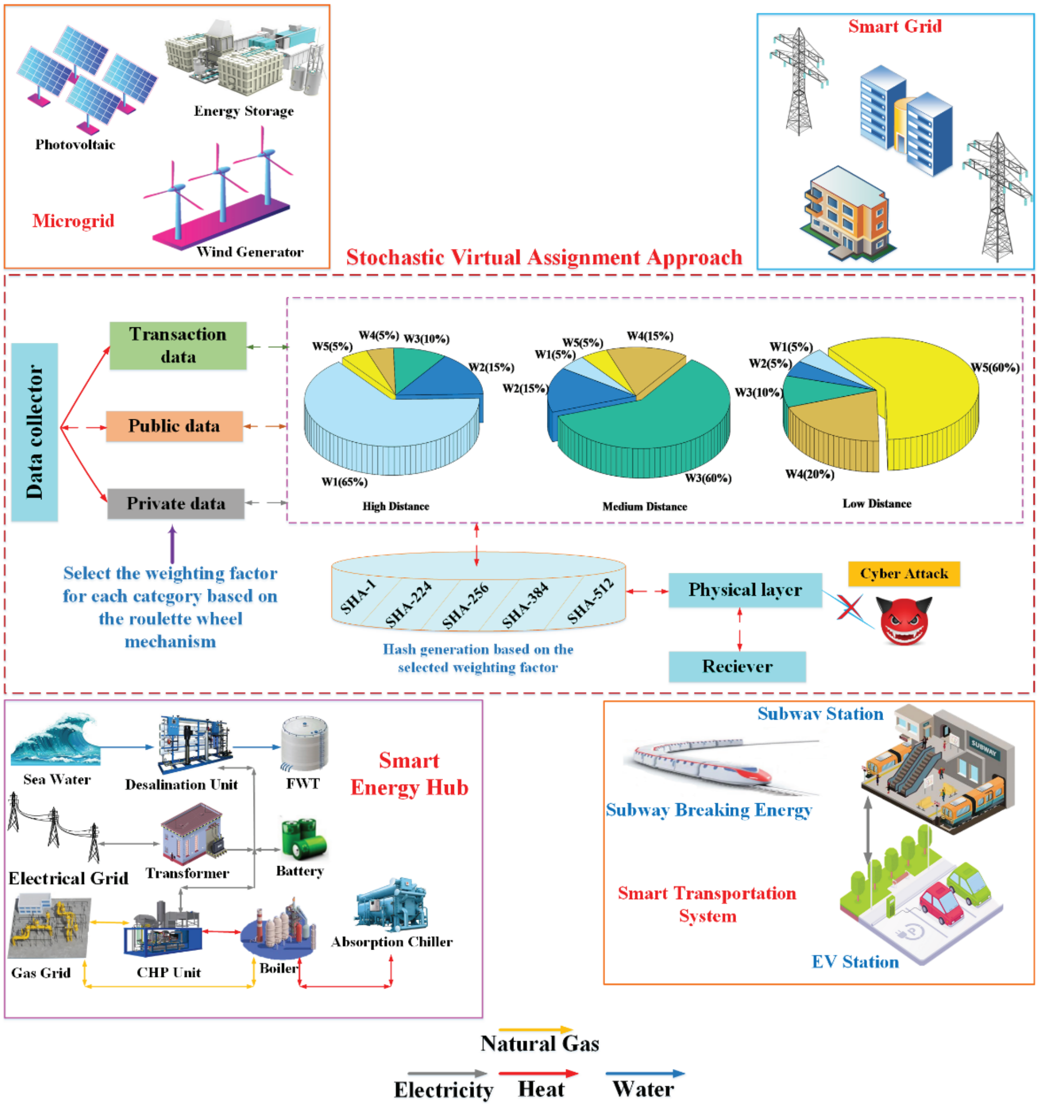


Fig. 7. Performance of the SVA method in smart city.

needed to generate the data block and t_{Mining} is the time takes to mine a data block. Worth a mention is $T_{tot-chain}$ which defines the total time process of the blockchain structure.

The proposed equation can be expanded to cover the time process of the SVA approach which can be expressed as (2).

$$T_{tot-chain} = \omega \times T_{sig} + (T_{back-off} + T_{trm}) \times 2 + t_{prod} + t_{Vir} + t_{Mining} \quad (2)$$

As can be seen the term t_{Vir} needs to be added to the total processing time namely the virtualization time, during which the proper hash function, in turn, the effective weight factor is obtained considering the Rolette wheel process. Also, the virtualization time is the time that it takes to virtualize the data block aiming to dissimulate the data block from any unauthorized node.

III. Mathematical Formulation of the Smart City

In this section the mathematical formulation governs the city is provided and discussed. Aiming to assess the performance of the SVA approach which is implemented among the smart city sections, this section is only organized to model the energy transaction between the sections of the smart city, data of which are transmitted and carried through the SVA platform. Hence only the power transaction and demand of the smart grid are needed to be modelled in the energy management problem of the smart city, which is validated in [17]. On the other hand, it is intended to provide a synergy framework for the smart city that has high number of energy exchanges with the aim of authenticate the performance of the SVA method in a more proper way. The total cost of the smart city is made up of different terms which are represented as follows:

$$cost_{Total} = cost_{Hub} + cost_{Subway} + cost_{EV} + \sum_{t} P_t^{Grid} \times price_{smart-grid} + cost_{Microgrid} \quad (3)$$

$$P_t^{Grid} = Load_t^{Grid} - P_t^{Microgrid} - \sum_{\substack{p\in\Omega^p \\ e\in\Omega^e}} P_{p,t}^{S2G} + P_{e,t}^{V2G} + P_{p,t}^{G2S} + P_t^{EHUB} \quad (4)$$

As it can be seen, the basic objective function of the smart city is represented by equation (3) which is comprised of five different terms including the operation costs of the EH, subway, EVs and the smart grid and microgrid, respectively. The main goal of the work is to provide a synergy mechanism among sections of smart city aiming to minimize the operation and investment costs of each section. The equation (4) expresses the balancing equation which mandatory to serve the smart city loads. On the other hand, all sections of the smart city are connected through the equation (4) and their related energy transactions are defined based on this equation. As mentioned earlier, the sections of the smart city try to transact energy with each other including vehicle-to-grid (V2G), vehicle-to-subway (V2S), subway-to-grid (S2G), subway-to-vehicle (S2V), and hub-to-smart grid. There are two types of parking lots, one of which is located in the metro stations and the other one in the smart grid, considered in this paper. The EH and microgrid systems are able to exchange energy with the EVs through the aforementioned smart grid's parking lot, which is described in equation (4). These energy transactions are considered to make the model more effective.

A. Smart Transportation Formulation

1) V2G & V2S Definition: The EVs can swap energy with the power grid to make profit, as stated. The underlying EVs profit is shown in (5) which is composed of three terms wherein the first term is V2G (6), and V2S (7), is the second term. The third term is the battery cost model of the EVs (8). The power capacity of the EVs' battery is depicted in (9) and (10), respectively for the grid-connected and subway-connected applications. In [6] $Vl_{p,r}$ is the power consumed by cars because of metropolitan traffic and $Vt_{p,r}$ is the energy generated by recharging lines. The constraints associated with the charging and discharging of EVs [11], [41] are as (11)-(20). The total energy exchanging of the EVs is imposed into the problem by using equation (21), (22). The objective and constrain are shown as follows:

$$f_V = f_{V2G} + f_{V2S} - \sum_{e\in\Omega^e} Cost_e^d \tag{5}$$

$$f_{V2G} = \sum_{t\in\Omega^t, e\in\Omega^e} (C_{V2G_{e,t}} \times P_{e,t}^{V2G}) \tag{6}$$

$$f_{V2S} = \sum_{t\in\Omega^t, e\in\Omega^e} (C_{V2S_{e,t}} \times P_{e,t}^{\mathrm{V2S}}) \tag{7}$$

$$cost_e^d = C_e^d \times \sum_{p\in\Omega^p, r\in\Omega^r, t\in\Omega^t} R(P_{r,e,t}^{V2G\_d} + P_{p,r,e,t}^{V2S\_d}), \quad \forall e \in \Omega^e \tag{8}$$

- *Constraints*

$$E_{e,t}^{V2G} = E_{e,t-1}^{V2G} + P_{r,e,t}^{V2G\_c} \times \eta_c - P_{r,e,t}^{V2G\_d} \times \eta_d \quad \forall r \in \Omega^r, \forall e \in \Omega^e, \forall t \in \Omega^t \tag{9}$$

$$E_{e,t}^{V2S} = E_{e,t-1}^{V2S} + \sum_{p\in\Omega^p, r\in\Omega^r} (P_{p,r,e,t}^{V2S\_c} \times \eta_c - P_{p,r,e,t}^{V2S\_d} \times \eta_d) - \sum_{p\in\Omega^p, r\in\Omega^r} z_{p,r,e,t} \times (Vl_{p,r} - Vt_{p,r}) \quad \forall p \in \Omega^p, r \in \Omega^r, \forall e \in \Omega^e, \forall t \in \Omega^t \tag{10}$$

$$E_{e,t}^{V} = E_{e,t}^{V2G} + E_{e,t}^{V2S} \quad \forall e \in \Omega^e, t \in \Omega^t \tag{11}$$

$$P_{e,t}^{V2G} = E_{e,t}^{V2G} - E_{e,t-1}^{V2G} \quad \forall e \in \Omega^e, t \in \Omega^t \tag{12}$$

$$P_{e,t}^{\mathrm{V2S}} = E_{e,t}^{V2S} - E_{e,t-1}^{V2S} \quad \forall e \in \Omega^e, t \in \Omega^t \tag{13}$$

$$u_{p,r,e,t}^{ch} + u_{p,r,e,t}^{dis} = ur_{p,r,e,t} \quad \forall p \in \Omega^p \; \forall r \in \Omega^r, \; \forall e \in \Omega^e, t \in \Omega^t \tag{14}$$

$$u_{p,r,e,t}^{ch} P_e^{ch,\min} \le P_{p,r,e,t}^{V2S\_c} \le u_{p,r,e,t}^{ch} P_e^{ch,\max} \; \forall p \in \Omega^p, r \in \Omega^r, \forall e \in \Omega^e, \forall t \in \Omega^t \tag{15}$$

$$u_{p,r,e,t}^{dis} P_e^{dis,\min} \le P_{p,r,e,t}^{V2S\_d} \le u_{p,r,e,t}^{dis} P_e^{dis,\max} \; \forall p \in \Omega^p, \forall r \in \Omega^r, \; \forall e \in \Omega^e, t \in \Omega^t \tag{16}$$

$$u_{r,e,t}^{ch} + u_{r,e,t}^{dis} = ug_{r,e,t} \quad \forall p \in \Omega^p, \forall r \in \Omega^r, \forall e \in \Omega^e, t \in \Omega^t \tag{17}$$

$$u_{r,e,t}^{ch} P_e^{ch,\min} \le P_{r,e,t}^{V2G\_c} \le u_{r,e,t}^{ch} P_e^{ch,\max} \; \forall p \in \Omega^p, r \in \Omega^r, \forall e \in \Omega^e, \forall t \in \Omega^t \tag{18}$$

$$u_{r,e,t}^{dis} P_e^{dis,\min} \le P_{r,e,t}^{V2G\_d} \le u_{r,e,t}^{dis} P_e^{dis,\max} r \in \Omega^r, \forall e \in \Omega^e, \forall t \in \Omega^t \tag{19}$$

$$E_e^{\min} \le E_{e,t}^{V} \le E_e^{\max} \quad \forall e \in \Omega^e, t \in \Omega^t \tag{20}$$

$$E_{e,t}^{V} = E_{e,t-1}^{V} + P_{e,t}^{V\_c} \times \eta_c - P_{e,t}^{V\_d} \times \eta_d \quad \forall r \in \Omega^r, \forall e \in \Omega^e, \forall t \in \Omega^t \tag{21}$$

$$E_{e,t}^{V} = E_{e,t}^{V2G} + E_{e,t}^{V2S}, \quad P_{e,t}^{V\_c} = P_{r,e,t}^{V2G\_c} + P_{p,r,e,t}^{V2S\_c}, \quad P_{e,t}^{V\_d} = P_{r,e,t}^{V2G\_d} + P_{p,r,e,t}^{V2S\_d} \tag{22}$$

2) S2G Definition: The subway revenue (23) is comprised by two factors: the benefit from the sale of BE's subway to the grid (24) and the expense of demand by the purchase of energy (25). The requirement for the subway can be met by purchasing the electricity from EVs and the grid. A bilateral contract between subway and the grid [17] demonstrated in (26) provides for the remainder of the supply. The subway's power transfer should not be exceeded by the subway BE (27). The objective and constraints are shown as follows:

$$f_{S2G} = f_{SG} - cost_{Subway} \tag{23}$$

$$f_{SG} = \sum_{p\in\Omega^p, t\in\Omega^t} (C_{p,t}^{SG} . P_{p,t}^{S2G}) \tag{24}$$

$$cost_{Subway} = \sum_{p\in\Omega^p, t\in\Omega^t} (C_{p,t}^{GS} . P_{p,t}^{G2S}) \tag{25}$$

$$L_{p,t}^{newsubway} = L_{p,t}^{subway} - P_{p,t}^{G2S} \quad \forall p \in \Omega^p, \forall t \in \Omega^t \tag{26}$$

$$P_{p,t}^{S2G} \le P_{p,t}^{BE} \quad \forall p \in \Omega^p, t \in \Omega^t \tag{27}$$

3) S2V Definition: This demonstrates the power transfer between the subway and the EVs. The profit for the subway is derived from the energy charged/discharged by the EVs (28). The equations (29)-(30) are analogous to those in the previous mode. The objective and constrain are shown as follows:

$$f_{S2V} = \sum_{p\in\Omega^p, r\in\Omega^r} C_{S2V_{e,t}} \times (P^{V2S\_c}_{p,r,e,t} - P^{V2S\_d}_{p,r,e,t}) \quad \forall p \in \Omega^p, r \in \Omega^r, \forall e \in \Omega^e, \forall t \in \Omega^t \tag{28}$$

$$P^{V2S\_c}_{p,r,e,t} \leq P^{BE}_{p,t} \quad \forall p \in \Omega^p, r \in \Omega^r, \forall e \in \Omega^e, \forall t \in \Omega^t \tag{29}$$

$$L^{newsubway}_{p,t} = L^{subway}_{p,t} - \sum_{r\in\Omega^r, e\in\Omega^e} P^{V2S\_d}_{p,r,e,t} \ \forall p \in \Omega^p, \forall t \in \Omega^t \tag{30}$$

B. Hub-to-Smart Grid

The CHP, boiler units and battery can be considered as different sections of EH. The operation costs of the hub-to-grid power transaction and gas are shown in (31)-(32). Also, the investment cost and total cost of the EH unit are represented in (33)-(34). The related constraints to the input active power of the EH and energy stored in the electrical storage of EH in time duration t are defined in (35)-(36) which will not allow the charging/discharging process being deviated from the nominal capacity of the energy storage. The stored energy of the battery during each time t obtained by (37) and the charging and discharging power limits of the battery are shown by (38) and (39).

The EH's energy storage cannot be simultaneously changed and discharged according to the constraint (40). In the EH system, the electrical and thermal power balance are shown in (41) and (42), respectively.

The natural-gas power is power input of the CHP and boiler systems that their power balance has been modeled in (38). The EH's energy conversion constraints are represented in (43)-(46).

$$cost_{transaction} = \sum_t (P^{EH}_t) \times price_{Grid} \tag{31}$$

$$cost_{Gas} = \sum_t (P^{GasIN}_t) \times price_{Gas} \tag{32}$$

$$cost_{Inv} = \sum_t \begin{pmatrix} C^{CHP}_t \times price_{InvCHP} \\ +C^{Boi}_t \times price_{InvBoi} \\ +C^{T}_t \times price_{InvT} \\ +\bar{S}^{ES}_t \times price_{InvES} \\ +C^{Ch}_t \times price_{InvCh} \end{pmatrix} \tag{33}$$

$$cost_{Hub} = cost_{Inv} + cost_{transaction} + cost_{Gas} \tag{34}$$

$$\underline{P}^{EHUB}_t \leq P^{EHUB}_t \leq \bar{P}^{EHUB}_t, \quad \forall t \in \Omega^t \tag{35}$$

$$\underline{S}^{Batt} \leq S^{Batt}_t \leq \bar{S}^{Batt}, \quad \forall t \in \Omega^t \tag{36}$$

$$S^{Batt}_t = \left(1 - \alpha^{loss}_e\right) S^{Batt}_{t-1} + P^{chBatt}_t - P^{dchBatt}_t, \quad \forall t \in \Omega^t \tag{37}$$

$$\frac{1}{\eta^{chBatt}_e} \underline{P}^{Batt} I^{chBatt}_t \leq P^{chBatt}_t \leq \frac{1}{\eta^{chBatt}_e} \bar{P}^{Batt} I^{chBatt}_t \quad \forall t \in \Omega^t \tag{38}$$

$$\eta^{dchBatt}_e \underline{P}^{Batt} I^{dchBatt}_t \leq P^{dchBatt}_t \leq \eta^{dchBatt}_e \bar{P}^{Batt} I^{dchBatt}_t \quad \forall t \in \Omega^t \tag{39}$$

$$0 \leq I^{chBatt}_t + I^{dchBatt}_t \leq 1 \quad \forall t \in \Omega^t \tag{40}$$

$$P^{eEH}_t = \eta^T_e P^{EHUB}_t + \eta^{GtoE}_{chp} P^{Gas_{chp}}_t + P^{dchBatt}_t - P^{chBatt}_t, \forall t \in \Omega^t \tag{41}$$

$$P^{h_{EH}}_t = \eta^{GtoH}_{chp} P^{Gas_{chp}}_t + \eta^{GtoH}_{boi} P^{Gas_{boi}}_t, \quad \forall t \in \Omega^t \tag{42}$$

$$P^{GasIN}_t = P^{Gas_{chp}}_t + P^{Gas_{boi}}_t, \quad \forall t \in \Omega^t \tag{43}$$

$$\eta^T_e P^{EHUB}_t \leq \bar{P}^{Tr}, \quad \forall t \in \Omega^t \tag{44}$$

$$\eta^{GtoH}_{chp} P^{Gas_{chp}}_t \leq \bar{P}^{CHP}, \quad \forall t \in \Omega^t \tag{45}$$

$$\eta^{GtoH}_{boi} P^{Gas_{boi}}_t \leq \bar{P}^{Boi}, \quad \forall t \in \Omega^t \tag{46}$$

C. Microgrid Formulation

As it was mentioned before, the microgrid system is another part of the smart city, formulations of which should be clearly stated in the model. The studied microgrid model comprises of WT units, PV power plant and energy storage system. The objective function of the smart grid is represented in equation (47) which is basically the investment cost of the microgrid system. As can be seen, four different terms form the objective function which are the operation cost of the PV units, WTs and storage system, respectively [17], [38]. The power balance of the microgrid is defined in (48). $P^{Microgrid}_t$ sums up the generated power of PV unit, WTs and energy storage system that is used in the total power balance equation (4). The output generated power of the PV unit is expressed by equation (49) which is based on the sun radiation DNI[38]. Also, the output power of the WTs is provided in (50) [38] which depends on the wind speed rate [42]. Finally, the output power of the storage unit based on its charging and discharging manners is resented in (51) [41], [39].

- Objective functions

$$OF_{Microgrid} = \sum_{t\in\Omega^t} (P^{PV}_t) Price^{PV}_t + (P^{WT}_t) Price^{WT}_t + (P^{bat}_t) Price^{bat}_t \tag{47}$$

- Constraints

$$P^{Microgrid}_t = P^{PV}_t + P^{WT}_t + P^{bat}_t \quad \forall t \in \Omega^t \tag{48}$$

$$P^{PV}_t = \frac{DNI \times C^{PV}_t}{G} \times (1 - lossPV), \quad \forall t \in \Omega^t \tag{49}$$

$$P^{WT}_t = \frac{1}{2} \rho A (SWT_t)^3, \quad \forall t \in \Omega^t \tag{50}$$

$$P^{bat}_t = P^{bat}_{t-1} + P^{cbat}_t - P^{dbat}_t, \quad \forall t \in \Omega^T \tag{51}$$

IV. Simulation Results

Firstly, the investigated smart city involves smart grids, smart transport systems, microgrids [17] and EH [21]. The microgrid consists of some generating units, including a PV system, a wind turbine (WT), an energy storage facility [35]. The WT is deemed to be implemented on the basis of the wind speed in [35]. As stated earlier, the EVs are permitted to

TABLE III

EVs Fleet Specifications in the Smart City

Fleet No.	EVs No.	Access Time	Capacity (kWh)		Charge and Discharge Rate (kW)	
			min	max	min	max
1	40	7-8,12-13,15-17	219	1644	7.3	292
2	63	7-10,12-14,17-19	263	1973	7.3	496
3	54	7-10,12-14,17-19	251	1902	7.3	386
4	33	12-14,16-18	208	1610	7.3	234
5	54	7-10,12-14,17-19	251	1902	7.3	386
6	39	7-9,12-14,16-18	219	1644	7.3	292

use the train station parking lots (TSPLs) and the grid parking lots of the EVs (GPLs). It is rational to presume various numbers of EVs, access time, and charge/discharge limitation of MSPLs as the technology and available time of arrival are supposed to differ between MSPLs [36].

The parameters of the EVs are shown in Table III [11] and energy prices of EVs' batteries are similar to the one stated in [37]. It is supposed that the EVs can access the TSPLs at two sequential terminals between train arrivals. The MSPLs need to be well placed between 6 considered metropolitan sites. In addition, for the EVs in the public transport system, two metropolitan paths–with a varying length and traffic jams–are regarded. The technical requirements and required load of the electricity grid are taken from [17]. All the simulations are executed in GAMS and MATLAB software and the overall mixed integer linear problem (MILP) is obtained by using CPLEX solver. This chapter contains three distinct case studies which evaluate accurately the efficiency of various components of the city. In accordance with the studied concepts of this paper, it's been attempted to prove the authenticity and performance of the SVA approach as a proper security platform and the proposed synergy mechanism within the smart city. To elaborate the introduced concepts, following case studies are provided where the first one is relevant to the SVA method and the other two cases will discuss over the synergy approach.

Case I: the SVA based data transaction in the smart city

Case II: energy exchange among transportation systems

Case III: energy transaction between EH and grid

A. Case I: the SVA Based Data Transaction in the Smart City

As mentioned before, the data transaction is based on the DAG approach in which the data are broadcasted within the private, public and transaction blockchains. Different weighting factors are considered for data transactions for different distances between the sender and receiver which is depicted in Fig. 8. In this regard, it has been assumed that the distances of the EVs-smart grid, EH-smart grid and microgrid-smart grid fall into the low distance, medium distance and high distance categories, respectively.

As mentioned in previous sections, for the case of high distances, the selection of the W_1 and W_2 is much more probable than the others. The same condition is valid for W_2, W_3 and W_4 in the case of medium distances and W_4, W_5 in case of low distances. According to Fig. 9, the probability occurrence of the weighing factors in each case is explicitly sorted and represented. In each case, the selection of the weighting factors is implemented based on the roulette wheel mechanism. With this in mind, the SVA method is exerted on the EV-smart grid (low distance), EH-smart grid (medium distance) and the microgrid-smart grid (high distance) as shown in Tables IV, V and VI, respectively. For each case, the selected weighting factors for the considered blockchains need to be different. In Table IV, the weighting factors for the private, public and transaction blockchains for the case of low distance data transaction are chosen as W_5, W_4 and W_5.

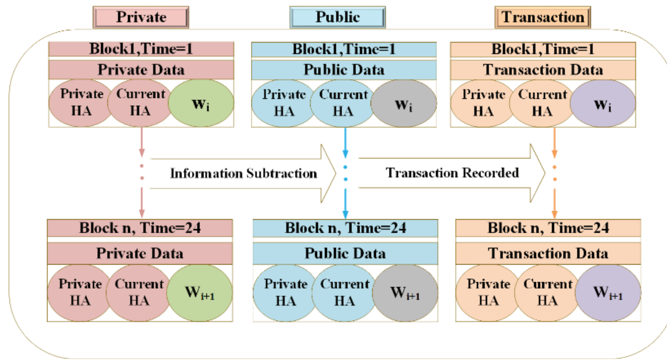


Fig. 8. SVA data transaction structure.

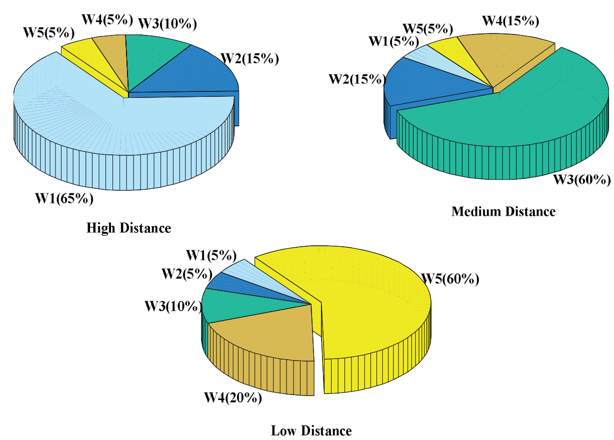


Fig. 9. Probability assignment of each weighting factor in roulette wheel.

TABLE IV

Data Blocks for Low Distance

Data Blocks	Time=10			
	Block information		Previous HA	randomly generated HA with SHA-384
Private	PV Gen.	WT Gen.	Current HA	randomly generated HA with SHA-384
	5324.2	928.294	Weight Factor	High Distance(W2) Block Label=2
Public	PV	4248	Previous HA	randomly generated HA with SHA-512
	Price ($/kWh)	2.75	Current HA	randomly generated HA with SHA-512
	WT	128	Weight Factor	High Distance (W1) Block Label =1
	Price ($/kWh)	3.28		
Transaction	PV to Grid	Wind to Grid	Previous HA	randomly generated HA with SHA-512
	4248	128.574	Current HA	randomly generated HA with SHA-521
			Weight Factor	High Distance (W1) Block Label =1

TABLE V
DATA BLOCKS FOR MEDIUM DISTANCE

Data Blocks	Time=16			
	Block information		Previous HA	randomly generated HA with SHA-224
Private	Boiler	CHP	Current HA	randomly generated HA with SHA-224
	36.6	250	Weight Factor	Medium Distance(W4) Block Label=4
Public	EH	Price ($/kWh)	Previous HA	randomly generated HA with SHA-256
	40.8	1.1	Current HA	randomly generated HA with SHA-256
			Weight Factor	Medium Distance (W3) Block Label =3
Transaction	EH to Grid		Previous HA	randomly generated HA with SHA-256
	40.81632		Current HA	randomly generated HA with SHA-256
			Weight Factor	Medium Distance (W3) Block Label =3

TABLE VI
DATA BLOCKS FOR HIGH DISTANCE

Data Blocks	Time=4			
	Block information		Previous HA	randomly generated HA with SHA-1
Private	Fleet	1 2 3 4 5 6	Current HA	randomly generated HA with SHA-1
	Ch/Dis Cost ($/kWh)	10 15 11 15 8 11	Weight Factor	Low Distance (W5) Block Label=5
Public	Fleet	1 2 3 4 5 6	Previous HA	randomly generated HA with SHA-224
	SOC%	80 55 80 49 64 80	Current HA	randomly generated HA with SHA-224
			Weight Factor	Low Distance (W4) Block Label =4
Transaction	Transportation (EV-Fleet)	Grid	Previous HA	randomly generated HA with SHA-1
	1	180.8	Current HA	randomly generated HA with SHA-1
	2	125.5		
	3	180.8	Weight Factor	Low Distance(W5) Block Label=5
	4	112.3		
	5	145.6		
	6	180.8		

The charging/discharging cost and SOC of the EV fleets and the energy transaction of the EV fleets with the smart grid is broadcasted through the private, public and transaction blockchains at the hour $t = 4$, respectively.

Table V shows the data block structure of the EH-smart grid energy transaction. Obviously it shows that the weighting factors for the private, public and transaction blockchains for the case of medium distance data transaction are chosen as W_4, W_3 and W_3.

The consumed power of the boiler and CHP, the extra generated power and the price of the EH and the energy transaction of the EH with the smart grid are chained to the private, public and transaction blockchains through the secured data blocks at time *16* as an example, respectively. Similar to the previous ones, Table VI represents the data block structure of the microgrid-smart grid energy transaction. For the case of high distance, the weighting factors for the private, public and transaction blockchains are chosen as W_2, W_1 and W_1. The generated power of the PV and WT, the extra generated power and price of the PV and WT and the energy transaction of the WT and PV with the smart grid are broadcasted to the private, public and transaction blockchains at $h = 10$, respectively. Such data transaction structure assures a secured energy transaction within the smart city against the serious cyber-attacks.

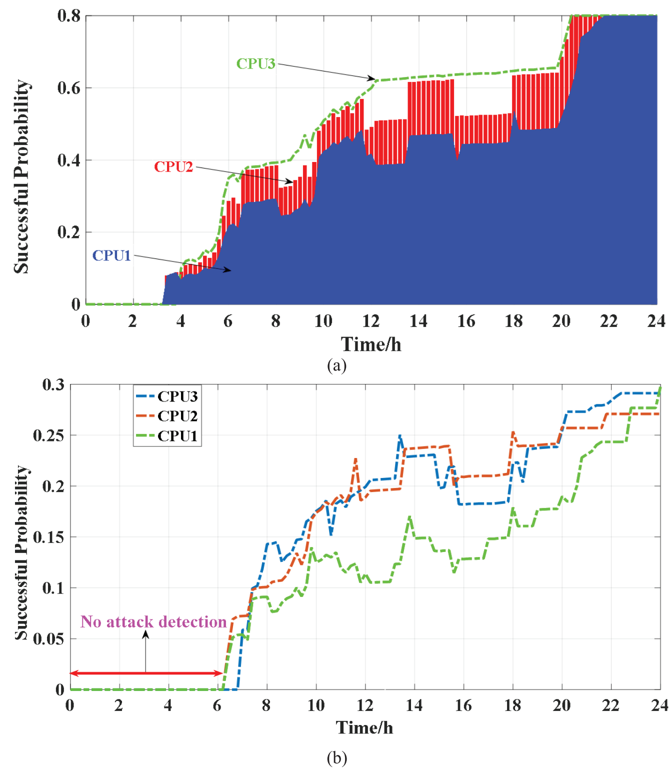


Fig. 10. The possibility of data attack a) DAG structure b) SVA structure.

This case study focuses on the validation of the proposed SVA scheme. Considering the DAG structure and SVA approach, a simulation is executed to find whether the SVA enhances the security or not. In this regard, suppose a network where nodes try to transact energy with each other. The simulation is performed considering three different CPU with different processing speeds where CPU3>CPU2>CPU1. The attacker as a third party attempts to manipulate the data which is transacted between the nodes of the system. This takes place before the data block is verified by the nodes.

Fig. 10 illustrates the successful probability of attack which is varied from 0 to 1. Fig. 10 (a) is the successful probability of attack considering the DAG structure and (b) depicts the successful probability of attack using the SVA approach. As can be seen, one worth mentioning point is the probability of success of the attack is reduced remarkably from 80% to 30% during some hours of the day. Another one, is the time that it took for the attacker to find out how to unsealed and manipulate the data.

It is evident that it consumed almost 6 hours for the attacker to apply any successful subversive action considering the SVA approach, which means the SVA at least increased the initial effective time for data decryption and manipulation for almost 50% compared to the DAG approach. All things considered, this shows that the SVA approach behaved as an effective barrier against the cyber threats which could effectively hamper their destructive activities. On the flip side, such barrier can provide a proper chance for the network to identify the unpermitted accesses.

B. Case II: Energy Exchange Among Transportation Systems

Since the transportation section includes the EVs and the subway, it demands to focus on the energy transactions between such systems within the smart city.

To have an optimal transaction between different sections, the profit maximization of each section should be considered, i.e., smart energy transaction between the EVs, subway and the smart grid. The BE of the subway plays a key role. Such regenerating energy can be used as a subway's demand supplement and profitable source through a contract with the smart grid. Constructing the TSPLs brings the chance of setting an opportunity to transact energy with the EVs by selling and buying the stored subway's BE.

Fig. 11 depict the energy transactions of the V2S, TSPLs and V2G for fleets 1, 2 and 6 as an example. The positive values show the discharging energy from the EVs to the subway which gains the EVs' profit and the negative values show that the EVs are charged by the subway's BE.

Comparing Fig. 11(a) and Fig. 11(c) shows that the EV fleets 2 and 6 are attempting to buy energy from the smart grid and seemingly sell it to the subway much more than that of the EV fleet 1. Hence, it's justifiable to mention that the EV fleets 1 passed the high traffic urban paths to the subway. Fig. 11(b) shows the overall energy transactions of the subway with the smart grid and the EVs through the TSPLs. Subsequently, it reveals that the subway had a higher chance of selling the energy to the EVs fleets in station 1 from hours 8 to 15.

Fig. 12 illustrates the deterministic (Case 1) and stochastic (Case 2) profit analysis of the S2G, V2S and V2G energy transactions within the transportation section considering the uncertain parameters of the transportation systems including EVs numbers, access time and the traffic jam, the microgrid, electricity and heat demands of the EH. It reveals that the uncertain parameters have led the S2G, V2S and V2G profit to be increased nearly by 1%, 3% and 2%, respectively.

C. Case III: Energy Transaction Between EH and Grid

The performance of the EH within the smart city is analyzed in this section. As mentioned previously, the EH has been comprised of a CHP, a boiler and an energy storage system.

Fig. 13 represents the demanded power of the CHP and the boiler to generate electricity and heat, respectively. The EH is capable of trading power with the smart grid which is shown in Fig. 13(a). The negative values express the energy consumption from the grid and the positive values show the injected power to the grid. The uncertain parameters of the smart city such as the transportation systems and microgrid probably can be affected by the other sections. Fig. 13(b) shows the performance of the EH considering the uncertain parameters. The stochastic analysis has led the heat and electricity demands of the EH to be increased. As it is shown in Fig. 13(b), such variation causes the EH power consumption during hours 1 to 13 and injection during hours 13 to 24 from/to the smart grid to be increased and decreased at some hours, respectively.

Table VII shows a comparison between the total number of variables and solution time of the study cases. It can be seen that the case study 3 has considerable number of variables compared to another study case due to greater scale of the model in the third study case.

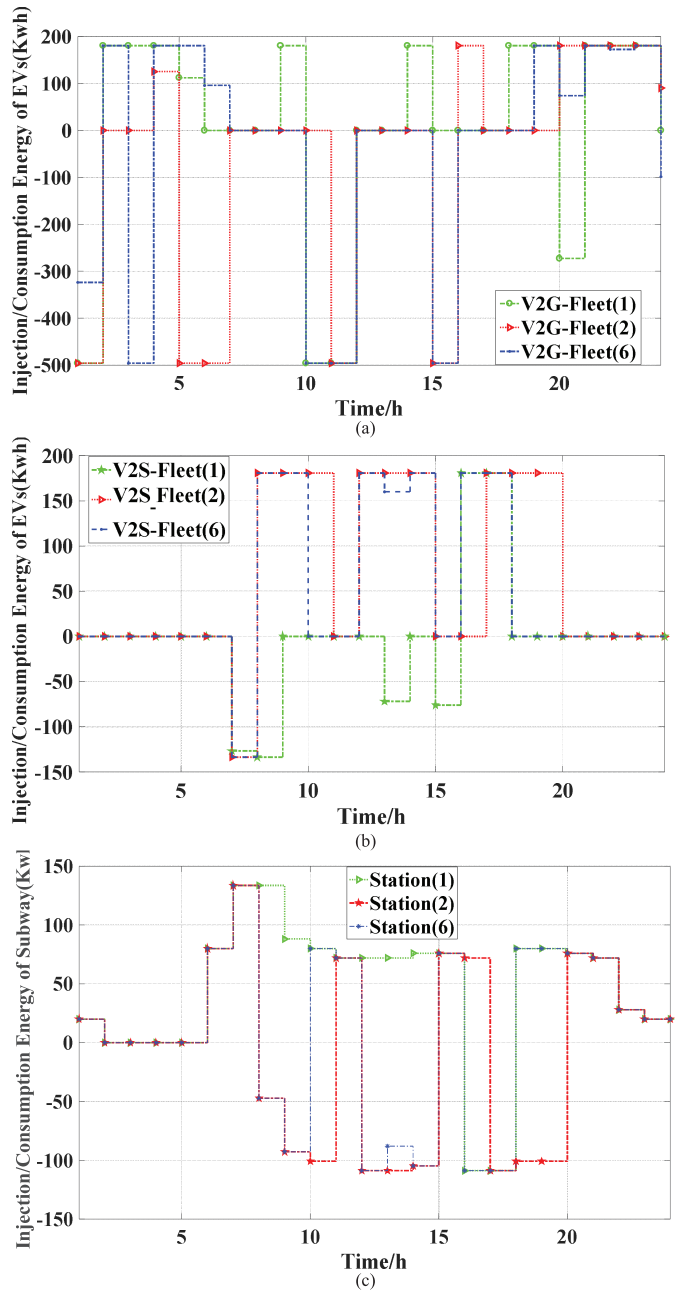


Fig. 11. Energy exchange patterns of fleets 1, 2, 6 for (a) V2G (b) V2S (c)TSPLs energy exchange with grid and EVs.

TABLE VII
NUMBER OF VARIABLES AND COMPUTATIONAL TIME OF STUDY CASES

Case Studies	Number of variables	Solution Time (s)
Case II	42,782	412
Case III	173,156	843
total	215,938	1255

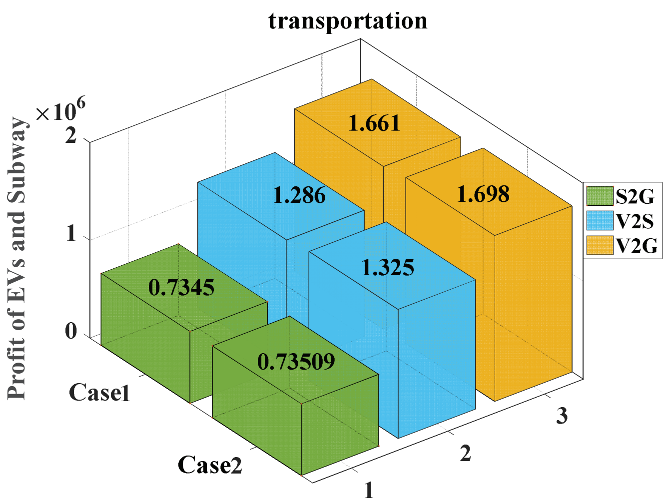
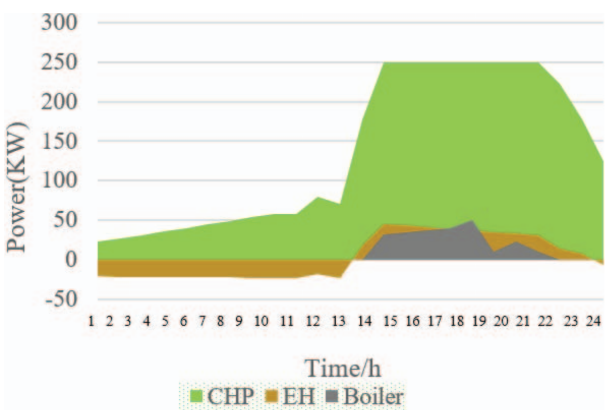
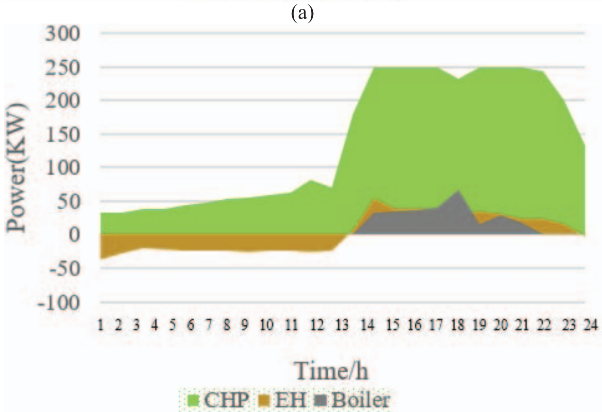


Fig. 12. Flowchart of the optimization procedure.



(a)



(b)

Fig. 13. EH energy trading with the grid a) deterministic b) stochastic.

V. Discussion

In this work, two main proposes are pursued including I) providing an effective synergy mechanism in the smart city and II) enhancing the security of data and energy transactions in such environment with vast number of data communication links. In this study, the SVA approach was implemented on a practical case drawn from [17] and based on the results, it was seen that the SVA approach could successfully decrease the possibility of data attacks in the transportation system of the smart city. In other words, considering the high number of EVs in the smart city and their relevant communication links, this method can be suitable and practical for securing the EVs in the transportation networks.

VI. Conclusion

This paper provided effective and secure energy transactions within a smart city. An accurate model which comprises of a microgrid, smart grid, smart transportation system and an energy hub was provided for the smart city. A stochastic virtual assignment approach based on a directed acyclic graph method was represented to assure the security of the energy transactions among different parts of the smart city while saving the energy and time of hash address generation through two proper strategies. This method has a few advantages compared to the normal blockchain technology. This approach is highly effective in the environments with vast number of data transactions and high possibility of data attacks that could be vulnerable against data frauds, which makes it extremely hard to tamper the data specifically in the transportation systems. However, considering the HA generation process in the SVA method for data security, it is expected to face with higher energy consumption of EVs' batteries where overwhelming such issue could be a future work. Hence, this approach is implemented in the smart city environment to provide a secure energy transaction scheme. In this regard, the previous and current hash addresses were generated and assigned virtually and randomly to each data block, which vary for each time-span of data transaction. It was shown that by the proposed method, the previous and current hash addresses would no longer be simply detectable for the data attackers. Also, in this paper a proper energy transaction framework was provided in which all parts of the smart city were linked and have energy transactions with the others. It was proven that by using the proposed SVA approach, the successful probability of the cyber-attack to the smart city had been reduced significantly and such approach created a barrier against the cyber threats and increased their initial time to detect and manipulate the data blocks. Due to the presence of various number of units in the future electricity markets which are intercommoned to each other for energy trading, this method is highly effective and stops cyber-attacks from frustrating the system, specificity in Peer-to-peer energy markets. Also, as a future work, such synergy mechanism can be used to enhance the resiliency of the smart city.

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