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Smart city data architecture for energy prosumption in municipalities: concepts, requirements, and future directions

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ABSTRACT
Big data is gaining visibility and importance, and its use is attaining higher levels of influence within municipalities. Due to this proliferation smart cities are posed to deploy architectures toward managing energy for Electric Vehicles (EV) and orchestrate the production, consumption, and distributing of energy from renewable sources such as solar, wind etc. in communities also known as prosumption. In smart city domain, Enterprise Architecture (EA) can be employed to facilitate alignment between municipality goals and the direction of the city in relation to Information Technology (IT) that supports stakeholders within the city. Hence, the alignment between IT and goals of the city is a critical process to support the continued growth and improvement of city services and energy sustainability. However, despite several research effort focused on data architecture in smart city, there have been few studies aimed at exploring how EA can be applied in smart cities to support residential buildings and EV for energy prosumption in municipalities. Therefore, this study conducts an extensive review and develops an architecture that can be employed in smart city domain based on big data management for energy prosumption in residential buildings and EV. Furthermore, secondary data was employed to present a case study to show the applications of the developed architecture in promoting energy prosumption. Findings suggest that the architecture provides interoperable open real-time, online, and historical data in facilitating energy prosumption. Respectively, this study offers exchange of data for sharing energy resources and provides insights to improve energy prosumption services.

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Sustainable energy; energy prosumption; smart cities; big data architecture; electric vehicles; residential energy management

1. Introduction

Presently, cities are one of the major contributors of climate changes. Due to the significant increase in global energy consumption, cities occupy 2% of the Earth, yet consume about 78% of energy emitting up to 60% of CO2 emissions (Haarstad and Wathne 2019). According to the United Nations (UN), 66% of the world population will reside in urban areas by 2050 (United Nations 2014), where about 75% of energy is consumed by cities generates 80% of the total greenhouse gases that causes adverse impact on the environment (Silva, Khan, and Han 2018). Hence, the energy sector is strategically important for the realization of the smart cities and currently this sector is experiencing changes, mostly due to the advent of smart grids from renewable sources that has resulted in change in the production, usage, and distribution of energy (Parag and Sovacool 2016). In a smart city, a smart grid manages two-way flows of energy, maintains energy consumption interactions between consumers and producers, and offers flexibility for the consumption and production of energy known as prosumption (Rathnayaka et al. 2013). The smart grid supports the exchange of data as information on energy flows, with improved proficiency by orchestrating peak demand, preventing power cuts, and decreasing energy load when needed. Respectively, smart grids are the backbone of smart cities and are responsible for autonomous management and operation of energy in municipalities (Karnouskos et al. 2011).

In Information Systems (IS) domain architecture mostly entails Information Technology (IT)-related artifacts such as software components, applications, hardware platforms, IT processes, services, and IT strategy that supports efficient IT operations in achieving return on IT investment toward creating value-added services to end users (Winter and Fischer 2006). Likewise, Enterprise Architecture (EA) aims to form an integrated IT environment (standardized software and hardware components) within the organization's business units (Lnenicka et al. 2017). More precisely, the goal of EA is to promote standardization, alignment, reuse of existing IT resources, and the sharing of common procedures within the organization (McGinley and Nakata 2015; Schleicher et al. 2016). Likewise, in smart cities EA can be a set of business processes that can facilitates municipalities to transform its energy prosumption mission and vision into effective sustainability wide change through distinct understanding of its present state and continuing toward achieving an improved future state (Lloret et al., 2016; Ta-Shma et al. 2017).

Respectively, in the context of the study EA in smart city defines the functionalities, interrelationship, and structure of all possible components, which deliver all expected energy related services to stakeholders. A stakeholder may be a citizen, group, company or municipality that is potentially impacted by or, has an interest in the operations of the city (Mamkaitis, Bezbradica, and Helfert 2016). Furthermore, smart cities generate vast

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amounts of energy data from Electric Vehicles (EV), sensor devices, traffic systems, metering devices, and domestic appliances that can be utilized to create integrated applications and services, thereby enhancing municipality's activities in making better use of available city resources (NathaLi et al. 2017). Accordingly, there is need to explore smart cities from the viewpoint of prosumers data processing of energy for EV and residential buildings. This is because big data is a fundamental requirement for smart city due to the huge volumes, velocity, variety, and value of data that are generated from systems and sensors deployed in municipalities (He et al. 2018).

Besides, in smart city thousands of residential and public buildings generate prodigious amount of data related to energy usage. Thus, analytics of big data is a practical solution to expedite real-time operation of energy services in smart city. Therefore, it is functional to outline the architecture of energy prosumption in smart cities from a data perspective to better describe important technologies deployed in smart cites (Cameron and McMillan 2013). Conducting research in big data is important as it contributes to the smartness of cities by linking and combining data from different sources, to obtain valuable insights to improve energy prosumption (Khatoun and Zeadally 2016). Also, data analytics utilizing big data is considered a crucial step toward a smarter city as it assures flexible and real-time data processing for intelligent decision procedures regarding energy prosumption operations (Da Silva et al., 2013a). This helps to provide data to consumers on their energy consumption and production level, allowing them to efficiently manage energy use (Espe, Potdar, and Chang 2018).

However, the effective and efficient use of generated data is challenging and raises issues such as enabling interoperability between multiple systems, ensuring citizens' privacy, managing large amounts of energy data, aiding the required scalability in smart cities to manage energy prosumption (Santana et al. 2018). Additionally, there are inadequate studies that concurrently explored energy prosumption, big data, and EA in smart cities domain toward achieving a positive energy district (Silva, Khan, and Han 2018). Accordingly, this study addresses this limitation by viewing smart city as an entity from the enterprise perspective by adopting and extending the concept of EA in organizations to cities, where an enterprise is applicable to smart city since municipalities just like enterprise have common goals such as improving the quality of life of citizens (Mamkaitis, Bezbradica, and Helfert 2016). Thus, this study aims to address the following research questions:

- What are the existing EAs that can be adopted to promote energy prosumption in smart cities?
- What are the implications of big data for energy prosumption in smart cities?
- Which literature has been proposed toward data architectures for energy prosumption?
- How can EA be employed to facilitate energy prosumption services in smart cities?
- How can big data be deployed to promote energy prosumption in smart cities?

Therefore, this study adds to the existing body of knowledge by developing architecture to improve openness of data by employing open real-time, online, and historical data, which focus mainly on the efficient distribution and storage of energy data to support prosumption operations in smart cities related to community buildings and EV in smart city. The proposed architecture supports smart city vision by exploiting Information Communication Technology (ICT) to achieve openness of data toward providing value- added services for citizens. It supports interoperability by providing open data sources in improving energy sustainability and living standards of citizens. Lastly, the architecture supports real-time intelligent data collecting, and energy customizing for autonomous decision making. The rest of this study was structured in the following manner: Section 2 is the literature review. Section 3 is methodology for energy prosumption in municipalities and Section 4 is the case study. Section 5 is the discussion and implications. Section 6 is requirements and future directions. Lastly, Section 7 is the conclusion.

2. Literature review

2.1. Background of enterprise architecture

An enterprise refers to the collection of organizations that work together in achieving a common set of goals. Whereas, architecture can be referred to as a design for the positioning of resources for facilitating institutional operations (Cameron and McMillan 2013). It entails the fundamental structuring of components, embodied in system, as well as the relationships and principles governing the components, protocols, and interface standards (Winter and Fischer 2006). Over the years EA has grown to include more than IT, the term evidently originates from IT area in a white paper on architecture of IBM System/360 dated back to 1964, which aimed to offer a holistic view of an organization (Greefhorst and Proper 2011). Accordingly, researchers such as Zachman (1996) defined architecture as a set of producible representations or artifacts that designate an object. Architecture helps to design and implement product based on quality, standards, and requirements. In the context of smart cities, the goal of enterprise architecture is to make IT more responsive and more strategic for citizens and stakeholders (Minoli 2008).

EA entails representation of the activities, resources, structure, information, processes, goals, and constraints of an organization (Zachman 1996). It involves a definitional and descriptive details of what should be and what is employed to explicitly define the institutional operations by providing data as information required for decision makers and stakeholders (Fox and Gruninger 1998). Hence, EA is a logical structure or template that classifies and organizes complex information in providing a blueprint of the present state of an organization that can be utilized to support decision making in the growth of strategy concerning the future state of the organization (Winter and Fischer 2006). EA provides a common structure, practices, terminology, and governance that stakeholders can consistently manage and follow based on a common vocabulary to help in planning and providing guidelines to measure and conduct a maturity assessment within organizations (Cameron and McMillan 2013). In addition, EA can be adopted as an instrument in municipalities' as a steering framework to coordinate the development and transformation of cities (Greefhorst and Proper 2011).

2.1.1. Review of existing enterprise architectures

EA is a representation of the relationship of a city's service operations to the processes and data that facilitates the services (McGinley and Nakata 2015). Over the years, several EAs have been proposed to address issues related to aligning, assessing, and managing enterprise objectives with technological strategies and requirements. Each EA has different weaknesses and strengths, which leads to difficulty in selecting an EA that is suitable for all situations. Accordingly, this section aims to achieve the first research question by reviewing and comparing selected EAs from the literature that can be employed for energy prosumption in smart cities.

2.1.1.1. Zachman enterprise architecture framework. The Zachman framework was presented by J. A. Zachman and it focuses on developing views rather than based on a methodology or process for the management of organizations (Zachman 1999). The Zachman framework was deployed based on a six-by-six matrix which comprises of what, how, when, who, where, and why as columns whereas the rows in the matrix entails six trans-formational views, which become more concrete and granular as one navigates downward from the views, which describes the actions which includes representation, identification, definition, configuration, specification, and instantiation (McGinley and Nakata 2015). Besides, in the Zachman framework each of the columns values represents a descriptive architectural model, which includes people, network, motivation, data, function, and time. Similarly, the rows denote the perspectives of the system, but not the perspectives of stakeholders. Thus, the Zachman framework is not a multi-dimensional stakeholder-based model that can explore the uncertainty, complexity, and normativity of societal problems such as energy prosumption in smart city. Therefore, the Zachman framework is not suitable as a base for the community architecture framework for the diverse stakeholders in smart cities (McGinley and Nakata 2015).

2.1.1.2. The open group architecture framework. The Open Group Architecture Framework (TOGAF) is a standardized approach for enterprise architecture and is maintained by The Open Group. A conglomerate of hundreds of enterprises covering both the nonprofit and profit sectors (TOGAF 2011). TOGAF was originally developed as a Technical Architecture Framework mainly for Information Management (TAFIM) as proposed by the United States Department of Defense. Accordingly, in 1995 the initial version of TOGAF was established as a progression of TAFIM. Ever since TOGAF has become a universal accepted framework, which is available freely (Cameron and McMillan 2013). Nowadays, enterprises such as HP, IBM, and SAP have employed TOGAF and improved it with their own architectural experience and knowledge. TOGAF can be adopted to provide detailed reference on enterprise architecture, which includes business, data, application, and technology layers (Greefhorst and Proper 2011). In addition, TOGAF standard has a distinct recommended standards, compliant products, and common vocabulary that assist the processing of EA implementation and is currently the most adopted EA framework in organizations (Cameron and McMillan 2013).

2.1.1.3. Gartner framework. Gartner assesses EA as an incessant process, which involves evaluating the current architectural state. Specifying objectives to create a future state and dealing with the complete portfolio continually during enterprise process (Sessions 2007). According to Gartner, EA is mainly a discipline that employs different strategies to develop a combined view of the organization that is in line with the business needs of an enterprise (Cameron and McMillan 2013). It includes architecting, business strategy, current-state architecture, environmental trends, governing, and managing. Furthermore, Gartner framework provides organizations with a logical method to develop an EA. It employs a multiphase, nonlinear, and iterative model that represents synthesis and key features of best practices of how the most effective enterprises have deployed and sustained their EA. Gartner framework is reliable and vendor-neutral. Also, enterprise can choose to adopt it with other enterprise framework. However, it does not address issue of what to develop, when, and how relationship (Bittler and Kreizman 2005).

2.1.1.4. Federal enterprise architecture framework. The Federal Enterprise Architecture Framework (FEAF) was developed as a legislation (the Clinger Cohen Act of 1994), also known as the Information Technology Management Reform Act which directed federal enterprises to design a master strategy for managing IT acquisitions, assimilating new technologies, assessing, and reporting on IT performance (Cisco 2009). FEAF aims to facilitate all US Federal Agency Chief Information Officers (CIOs) to design, develop, and implement an integrated architecture to exploit the value and reduce risks related to IT projects. The first version of FEAF was made public in 1999 after which it has been modified and expanded over time (Council, 1999). Due to the diversity of concerns that federal enterprises deal with and several levels of measure at which the federal government level, FEAF is multilayered, complex, and large. It consists of a collection of management strategies expressed in IT terms more than a formal methodology or taxonomy. It can be viewed as a methodology for developing EA as well as the outcome of applying that process to a specific enterprise namely the United State government (Cameron and McMillan 2013). Besides, FEAF includes all necessary initiatives needed to design an EA and is suitable for more complex enterprises. Moreover, FEAF attempted to achieve a seamless incorporation of various architectures that existed in different federal agencies to connect all stakeholders involved by supporting better and faster access to information in a more profitable manner (Cameron and McMillan 2013). It comprises of performance, business, components, technology, and data layers (Cisco 2009).

2.1.1.5. The department of defense architecture framework. The Department of Defense Architecture Framework (DoDAF) was founded in 1990 as Command, Control, Communications, Computers, and Intelligence (C4ISR) to support interoperability. The DODAF can be referred to as holistic and conceptual model for supporting the development of EA particularly for Department of Defense (DoD) agencies. DoDAF employs a high-level view model that comprises of three individual views which includes operational, systems, and technical to define an artifact. DoDAF helps in visualizing and describing architectural complexities that exists in graphics, text, and structure (Cameron and McMillan 2013). Although, DoDAF is grounded on three main views, a fourth view referred to All View supplements the other views by providing connection between the views by employing a dictionary to define specific terms to provide summarized, or contextual information (Urbaczewski and Mrdalj 2006).

DoDAF provides guidance and rules for consistency descriptions in achieving final products. Thus, ensuring that a common term is used for comparing and integrating different systems, as well as systems of systems to achieve interoperability and interaction of systems (Rouhani et al. 2013). Conceptually, DODAF is analogous to FEAF in practice, but it was developed for a specific enterprise and was not developed to be utilized beyond those bounds. In comparison to other framework such as TOGAF and Gartner which were developed to address general issue within EA development across different organizations. DODAF was designed to solve a wide array of specific issues within a singular organizational context (Urbaczewski and Mrdalj 2006). DODAF provides a model-driven template that can be used to aggregate and transfer data based on a specific architectural area. It also comprises of a view model to be employed as a facet for supporting and guiding decision makers in strategic or tactical issues (Rouhani et al. 2013).

2.1.1.6. The oracle enterprise architecture framework. The Oracle Enterprise Architecture Framework (OEAF) encompasses a collection of valuable solution architecture artifacts that facilitates Oracle's broad services and products portfolio. OEAF was developed based on the influence of TOGAF, FEAF, and Gartner framework to provide efficient, business-driven approach in helping stakeholders align IT and business strategies (Oracle 2009). OEAF supports Oracle to collaboratively work with clients to develop a strategic roadmaps and architectural solutions that aligns business and IT. Thus, by focusing on business outcome and IT assets OEAF can be employed to proficiently create an architecture roadmap for employing enterprise-driven business solutions (Oracle 2009). OEAF corresponds to other EA frameworks by clearly mapping FEA and TOGAF, such that customers can use OEAF framework to influence the strengths of the different frameworks and integrate it with Oracle's experience in designing enterprise solutions. (Oracle 2009). Furthermore, OEAF provides an architectural structure for disseminating Oracle's vast intellectual capital related to enterprise IT solutions with its clients and associates, thereby improving Oracle's strategic enterprise value proposition. Thus, fostering agile enterprise architecture capabilities in linking business requirements to IT initiatives in achieving organizational goals. OEAF includes business, application, information, technology layers, as well as EA repository, governance, people, process, and tools (Oracle 2009).

2.1.1.7. Generalized enterprise reference architecture and methodology. The Generalized Enterprise Reference Architecture and Methodology (GERAM) involves tools, models, and methods, which are required to implement and maintain single, virtual, extended or integrated enterprises (IFIP–IFAC 1999). GERAM aims to design and maintain the entire enterprise lifecycle by integrating knowledge while supporting enterprise to identifying overlaps and adding value. The GERAM lifecycle comprises of identification, concept, requirements, design, implementation, operation, and decommission. GERAM employs a pragmatic approach that provides a comprehensive framework for describing the elements needed in enterprise engineering for enterprise integration processes (IFIP–IFAC 1999). In addition, GERAM is proposed to simplify the integration of several domains to allow their collective use, as opposed to isolated usage. Hence, GERAM unifies two distinct approaches of enterprise incorporation, those rooted in product models and those related to business process development. GERAM also offers insights into enterprise integration as well as the relationship of integration with other strategic operations in enterprise engineering for improvement of enterprise activities and adaptation to societal changes (IFIP–IFAC 1999).

2.1.2. Comparison of enterprise architectures

This section aims to compare the reviewed EAs (see Section 2.1.1), based on a set of criteria that relates to both generic EA features and attributes which comprises of "concepts, modeling, and process" as recommended by Sessions (2007); Cameron and McMillan (2013); Rouhani et al. (2013). Correspondingly, the concept of EA is generally important for enterprises in selecting the most suitable modeling approach. According to the literature (Winter and Fischer 2006; Rouhani et al. 2013; Lloret et al., 2017; Ta-Shma et al. 2017), EA are assessed based on the definition/purpose, provision of repository, supports alignment between business and IT, facilitates communication and association among artifacts and strategy, process linking, strategize governance, and roles.

Modeling provides the basis for EA and portrays designs that relates to EA concepts which is generally the main constituent of any EA. Modeling is an important part of architecture development that need to be employed in EA (Rouhani et al. 2013). Accordingly, using the most appropriate modeling could decrease inherent complexities of present and proposed architecture, as well as aid effective transition plan for enterprise architect and IT analysts. A typical EA modeling comprises of the following main elements (semantics, syntax, and notation) (Lagerström et al., 2009; Rouhani et al. 2013). Similarly, EA highlights the set of process and components involved in EA life cycle. These activities formulate the process, which directs enterprise architect and IT analysts in EA implementation. A useful EA should encompass current architecture analysis, enterprise modeling, managing and providing detailed design of projects, desired architecture analysis, describing implementation control and transition plan (Rouhani et al. 2013).

Therefore, each of the reviewed seven EAs are compared in relation to their concepts, modeling, and process factors derived from the literature (Cameron and McMillan 2013;

Rouhani et al. 2013; Sessions 2007). Based on a predefined EA assessment scale, where (5) is high consideration or clear and detailed description, (3) is medium consideration or average description, and (1) is little consideration or low-level description as suggested by Rouhani et al. (2013). Thus, Table 1 depicts the comparison of the selected EA frameworks.

Based on the comparison of prior EA frameworks based on concepts, modeling, and process as seen in Table 1 the results suggest that TOGAF is the most suitable EA with a score of 67. The scores on each of the EA are obtained mostly from prior rating from the literature (Cameron and McMillan 2013; Rouhani et al. 2013; Sessions 2007), and are combined as shown in Table 1. Accordingly, this study opted to adopt and extends TOGAF analogous with prior studies (Cameron and McMillan 2013; Greefhorst and Proper 2011; Mamkaitis, Bezbradica, and Helfert 2016). This is because TOGAF is based on frequent and latest used practices in EA domain and has a well-established industry standard, which is designed by the consortium of corporations.

TOGAF is divided into 4 layers (business, data, application and technology) which can be adopted to energy prosumption in smart cities in defining procedures for developing robust architecture principles for energy prosumption. Although, TOGAF is insufficient in its original form to address energy prosumption in smart cities it can be extended to encompass other appropriate layers that contain elements that are necessary to design theoretical and practical smart city data architecture in addressing energy sustainability in municipalities context. Also, TOGAF is simpler to implement and involves technical and non-technical stakeholders such as residential prosumers, energy retailer, energy service provider, etc. as seen in Figure 7.

2.2. Overview of smart city

A city can be referred to as smart when city services and operations such as transportation and electricity grid are managed through ICT to improve efficiency and ease of operation (Khatoun and Zeadally 2016). Thus, research and development related to smart city has increased in the last few decades, due to dramatic urbanization. A smart city can be defined as an urban environment that utilizes ICT and other associated technologies to improve the performance effectiveness of city operations and services provided to urban citizens (NathaLi et al. 2017). The development of smart cities can be dated back to 1990 s when the term was proposed to highlight urban development toward innovation, technology, and globalization (Bokolo and Petersen 2019). Since then smart cities have received considerable attention but was further popularized in 2009 when IBM proposed the corporate strategy of Smarter Planet, which later gained wide support from scientific and industrial domain (Rathnayaka et al. 2013).

Therefore, smart city refers to an advanced modern city that deploys ICT and related technologies to improve the quality of life, operational efficiency of municipality services (NathaLi et al. 2017). While ensuring the resource availability for present and future generations in terms of environmental, economic, and social aspects (Jnr, Majid, and Romli 2018). Furthermore, smart city aims to utilize public resources efficiently to increase the quality of services provided to urban citizens, where the services offered such as mobility, electricity, and so forth (Santana et al. 2018). Thus, smart cities are seen to provide innovative solutions to address the challenges of sustainable development in urban regions (Anthony and Petersen 2019). In other words, smart cities are anticipated to address diversity of urban challenges faced by cities to increase innovation, competitiveness, and rates of economic growth while realizing sustainability goals such as increased energy efficiency, decreased CO2 emissions, and improved quality of life (Haarstad and Wathne 2019).

Table 1. Comparative analysis of reviewed EAs.

Components	Indicators	Zachman	TOGAF	Gartner	FEAF	DoDAF	OEAF	GERAM
Concepts	Business-IT Alignment	5	3	3	1	3	5	1
	Artifacts Interoperability	5	5	3	3	3	3	1
	Governance Support	1	1	5	1	3	3	1
	Repository Information	1	5	3	3	3	5	1
	Layers Integration	1	5	3	3	3	3	1
	Vendor Neutrality	1	5	5	1	1	5	1
	IT Strategy	5	3	5	5	5	3	3
Modeling	Easy to use	3	3	3	3	3	3	1
	Easy to learn	1	3	3	3	3	1	1
	Traceability	3	3	1	3	1	1	1
	Standard Consistency	3	3	1	3	1	1	3
	Different Views	5	3	3	3	3	3	3
	Process Completeness	3	3	1	1	1	3	5
	Dynamic Maturity	3	3	1	1	1	1	1
Process	Requirement Flexibility	5	5	1	1	1	1	5
	Step by Step	5	3	3	3	3	1	5
	Detailed Design	5	3	3	3	3	3	5
	Implementation	3	3	3	3	3	3	3
	Guidelines	1	5	1	5	3	3	3
	Maintenance	1	3	1	3	3	1	1
	Continual	1	5	1	1	1	1	1
Total Assessment		**61**	**67**	**53**	**53**	**51**	**53**	**47**

For rating scale 5 = high consideration, 3 = medium consideration, 1 = low consideration

2.3. Energy prosumption in smart cities

2.3.1. Smart grid for energy prosumption

The demand for electricity in the world is constantly rising. Global energy consumption is predicted to increase by 49% by 2035 (Zafar et al. 2018). Thus, improving electricity efficiency and decreasing the use of fossil fuels have attracted significant attention worldwide, due to energy crisis and the deteriorating environment (Rathnayaka et al. 2014). Thus, smart grids have opened a new role of prosumers in the energy system, changing ordinary energy users into prosumers. According to the European Union (EU) the smart grid is an electricity network, which autonomously manages the actions of consumers and generators connected to it to proficiently provide secure, economic, and sustainable electricity supplies (Ardito et al., 2014). Likewise, the US Department of Energy defined the smart grid as a self-healing, active involvement of consumers, which operates robustly against natural disasters and attack, accommodates storage options and generations, supports integration of new energy-based services, products, and markets, optimizes asset usage and operates proficiently to provide quality energy for the digital economy (Menniti et al. 2014).

Figure 1 depicts the desirable characteristics of smart grid, which includes self-healing in which the smart grid quickly detects interruptions and recovers quickly from them. Also, the smart grid is resistant and mitigates cyber-attacks by being resilient to virtual security attacks and it improves energy distribution by facilitating plug-and-play to simplify interconnection process (Liu et al., 2017). Lastly, it offers flexible user-friendliness energy services to consumer, energy distributors, and marketers (Rodríguez-Molina et al. 2014). In summary, the smart grid can be referred to as integration of electricity infrastructures and is categorized with a bi-directional flow of information (data) and energy and involves an intelligent power system fused with an integrated communication system (Anthony et al. 2019; Soltani et al. 2019).

Furthermore, the smart grid aims at providing a sustainable, secure and economic power supply with the active involvement of consumers (Hassan, Khan Afridi, and Irfan Khan 2019). It deploys an electricity network that can autonomously integrate the actions and behavior of all stakeholders (producers and consumers) connected to it to deliver secure, economical, and sustainable energy supplies (Zafar et al., 2018). Hence, the smart grid differs from the traditional energy grids, which mainly focused on the communications between distribution system operators, transmission system operators, and generators (Karnouskos et al. 2011). Besides, it is imperative to note that energy consumers are not active participants in this traditional model (Anthony Jnr et al. 2020). In the traditional grid energy-consumers only consume electricity supplied by an energy company and pay the electricity bill. Whereas in the smart grid citizens not only utilize energy but also produce and supply energy back to the grid (Haji et al. 2019; Ma et al. 2016).

Figure 2 depicts a conceptual view of a smart grid and its associated components, which comprises mainly of solar power, electric vehicles, wind power plant, and smart houses. Thus, smart grid employs ICT with advanced power electronic infrastructures to deploy a bidirectional flow of information and electricity as seen in Figure 2.

2.3.2. Energy prosumption in smart cities

Over the years, global energy demand has significantly increased across all sectors (Jnr et al. 2020). In residential area, electrification is a vital contributor to the increasing energy demand. Thus, EU prescript that efforts should be made to decrease carbon emissions and increase the uptake of renewable energy to address climate change (Karnouskos, 2011). Hence, European countries have set an ambitious goal to improve energy sustainability toward addressing the increased energy needs of its citizens. This has resulted to swift application and deployment of renewable energy technologies (Kotilainen, Mäkinen, and Valta 2017). In residential areas, this tendency has established itself in the increase use of Photovoltaic (PV) systems on residential buildings rooftops. Additionally, there is a strong awareness toward renewable energy resources and decline in dependence of traditional energy sources (Zafar et al. 2018). Renewable energy generated using solar, wind, etc. produced by consumers can be utilized as clean source of energy and can be shared to other citizens

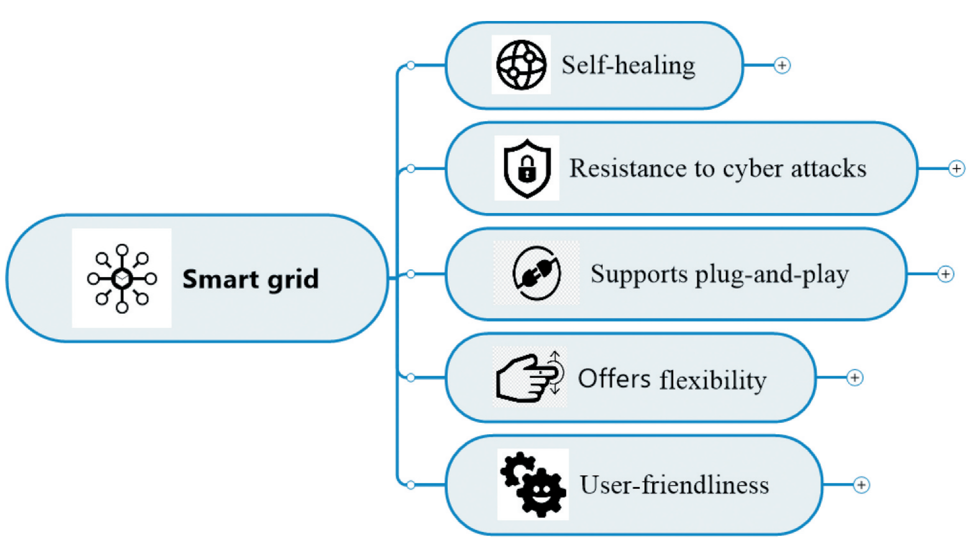

Figure 1. Characteristics of smart grid.

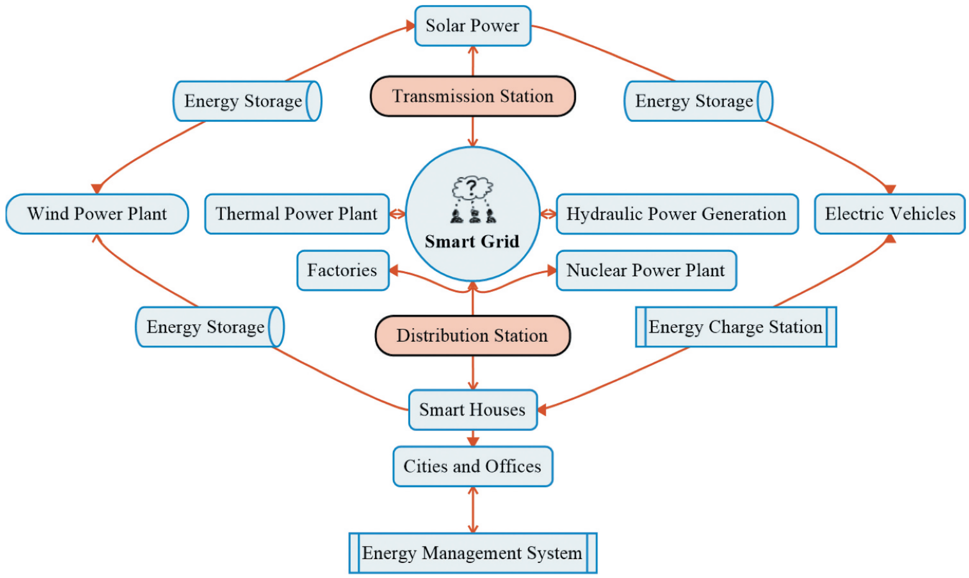

Figure 2. A conceptual view of smart grid.

and the grid. Thus, a consumer who produces and shares energy in municipality can be referred to as a prosumer (Liu et al. 2017). Accordingly, prosumers are citizens that both produce, consume and energy as seen in Figure 3. The prosumers consume and shares excess energy generated from renewable energy sources with the grid or/and with other consumers in the community (Razzaq et al., 2018). Prosumption helps address environmental, economic, and social issues related to increased energy demand managed by the smart grid (Da Silva et al., 2013).

Thus, the role of citizens' engagement is changing, as energy consumers can now become energy producers in energy markets through installation of solar PV panels (Kotilainen, Mäkinen, and Valta 2017). In smart cities the prosumers have emerge as vital actors in the energy industry by storing produced energy mostly in a battery or in EV for own use or for later sharing with their neighbors in the community (Parag and Sovacool 2016). Furthermore, the prosumers in the neighborhoods will increasingly play a crucial role in smart cities, as they are required to autonomously manage their energy resources and services (Ma et al. 2016). Based on prosumption activities in community neighborhoods the production of solar PV panels has continued to rise from 3,700 MW to more than 150,000 MW within the decade (Mamkaitis, Bezbradica, and Helfert 2016; Santana et al. 2018).

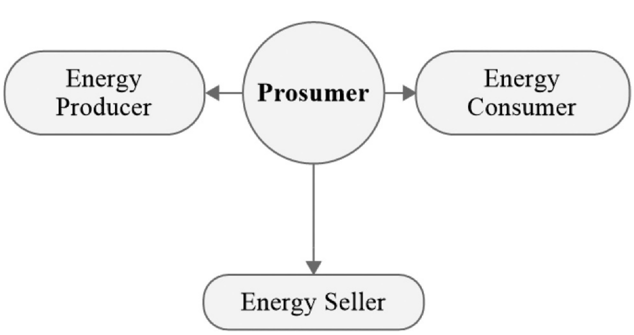

Figure 3. Overview of energy prosumer approach.

Concurrently, there are emerging energy markets and opportunities for residential energy storage solutions such as the current unveiling of the Tesla home-based battery that, together with EV battery have the potential to improve energy sustainability and increase citizens benefits (Parag and Sovacool 2016). This development in the electricity market offers an unparalleled prospect for synergistic, positive interactions through the smart grids (Haarstad and Wathne 2019). However, there has been very little inquiry in developing big data architectures to facilitate energy prosumer and existing approaches do not effectively provide information on how energy prosumption can be individually managed in smart cities.

2.3.3. Mobility as a service for electric vehicles prosumption

Mobility focuses on serving the transportation needs of cities by considering the sustainability of vehicles powered by a portable energy source that can differ in the usage of electrification (Kamargianni and Matyas 2017). Similarly, Mobility as a Service (MaaS) aims to address the gap between private and public transport operators in a city, intercity and nationwide level, and involves the integration of services to citizens of a city such as access to real-time booking and payment data (Li et al. 2017). Currently, sustainable mobility services are considered a crucial component in smart cities to improve energy proficiency of transportation systems while decreasing carbon emissions (Bellekom, Arentsen, and van Gorkum 2016). Moreover, with increased concerns on protecting the natural environment and exhaustion of fossil energy for mobility services, EV are utilized as a more sustainable alternative for mobility services. Electrification of vehicles has gained significant investments from both governments and car manufacturers (Kotilainen, Mäkinen, and Valta 2017), since combustion-based engine vehicles pollutes air quality. Whereas EV are energy efficient, produce less noise, and eliminates pollution. EV aim to achieve zero emission and can be maximized by charging with renewable energy sources such as hydroelectric, wind, solar, etc. (Bohnsack, Pinkse, and Kolk 2014).

Therefore, EV transition is predicted to enhance energy security and trade balance of states by reducing oil import as well as facilitates the utilization of renewable energy and batteries of EV as energy storage. Hence, the electrification of vehicles has been prioritized in several European countries (Dijk, Orsato, and Kemp 2013). Additionally, EV owners can further generate their own energy from solar PV panels installed on their own homes. The energy generated from renewable sources can be commercialized to community neighborhood within the smart grid or used by the homeowner (Bellekom, Arentsen, and van Gorkum 2016; Kotilainen, Mäkinen, and Valta 2017), as seen in Figure 4. Such flexibility presents prospect for improving the orchestration of the entire electric systems. EV can be deployed to reserve and supply energy based on bidirectional energy transmission between the vehicle, home or smart grid, usually referred to as V2 G. Thus, Vehicle-to-Grid (V2 G) can boost the income for EV owners, promoting its adoption, and improving the stability of smart grid (da Silva and Santiago, 2019).

Additionally, EV can also store energy based on V2 G that supports EV to not only charge its battery from the smart grid as Grid-to-Vehicle (G2 V). But, also supply energy to the grid and when connected to the smart grid EV can basically serve as loads on demand or as generators (Dijk, Orsato, and Kemp 2013). Evidently, the viability of using EV for domestic or grid-based energy services depends on the magnitude and volatility of energy prices in the current energy market. However, current studies related to EVs are mostly technically energy oriented with less perspective on data or the viability of big data to improve energy services of EV, home or smart grid (Li et al. 2017), as seen in Figure 5. Thus, there is need for a study that addresses this gap between theory and practice of EV energy and data services. Thus, this study employs EA as an approach to address this gap in knowledge.

2.4. Applicability of big data for energy prosumption

This section aims to provide answer to the second research question by exploring the significance of big data for energy prosumption. Big data can be referred to as a set of tools and techniques employed to manipulate and store large data sets, which conventional technologies, such as sequential handling and relational databases systems cannot process (Santana et al. 2018). Energy systems, devices, and sensors generate huge amounts of data with various measures of complexity from various sources at different velocities, which cannot be analyzed with traditional technologies, which leads to the general classification of big data (Silva, Khan, and Han 2018). Big data

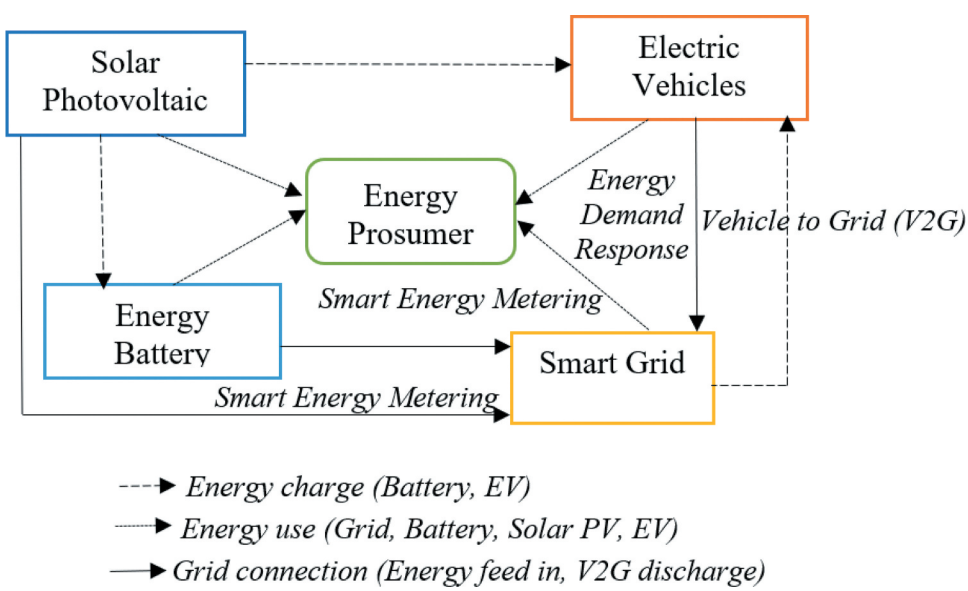

Figure 4. EV prosumption approach in smart city adopted from.Kotilainen, Mäkinen, and Valta (2017)

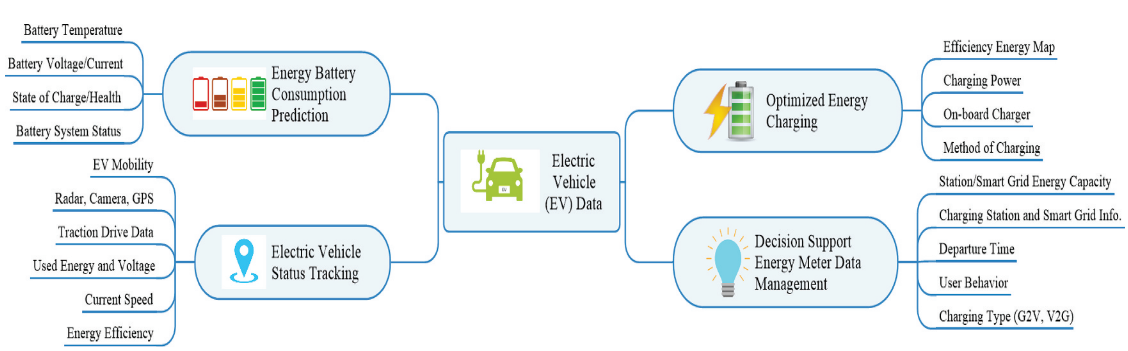

Figure 5. EV prosumption data sources in smart city adopted from.Li et al. (2017)

possess the capability to support energy prosumption in smart cities (Ta-Shma et al. 2017). Where big data can facilitate an environment for collaboration among prosumers in a community, ease information availability, enhance interoperability of energy technologies from different vendors and seamless experience for citizens in the city (d'Aquin, Davies, and Motta 2015). Thus, data collected from heterogeneous sources such as energy metering devices, appliances, etc. can be utilized by consumers in making decisions on energy consumption and trading (Costa and Santos 2016; Silva, Khan, and Han 2018). There are four main characteristics of big data, which comprise of volume, velocity, variety, and veracity as presented in Figure 6.

Accordingly, Figure 6 depicts the four major characteristics of big data each of which are briefly discussed below;

- Volume: The amount of data produced and collected from devices is rapidly increasing, and technologies are required to address this challenge. In energy prosumption, the volume of data is massive since energy is used in residential building, EV, and data originates from many dispersed data sources.

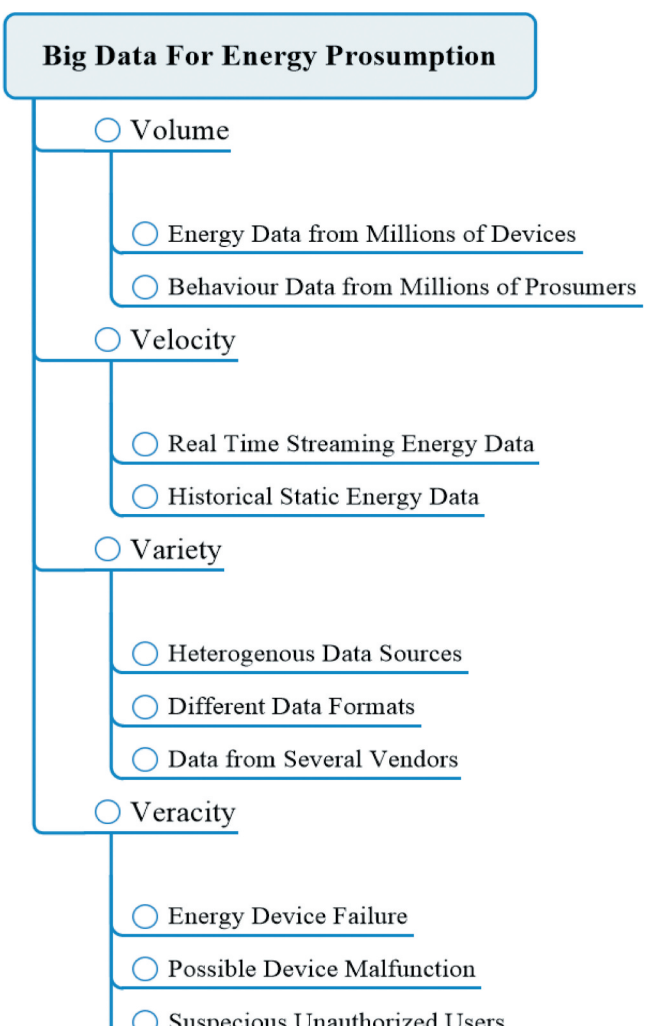

Figure 6. Four Vs of big data in energy prosumption adapted from.Santana et al. (2018)

- Variety: Data collected from energy sources in smart cities comprises of structured, semi-structured, or unstructured formats, such as power usage records, EV charging data, and data from consumers respectively. These poses a challenge in integrating these data into an operability format for decision making for consumers.
- Velocity: Data generation from energy devices is fast, and in some cases, these data are streamed in real time, which makes the data difficult to analyze for energy prosumption services. Thus, there is need for prosumers to be able to analyze and rapidly respond to data from devices such as metering devices to support energy trading in the smart grid.
- Veracity: Due to the large amount of data generated and the use of various data sources. It is important to ensure that the collected data possess quality, since errors in the data or the use of unreliable data sources can compromise the analysis, which may affect energy prosumption services in smart grid. In smart cities, poor data sources can consist of incorrect energy metering readings, malfunctioning energy sensors, and malicious handlers.

Furthermore, there has been increased discussion regarding how to make energy data open, effective, and useful in smart cities (He et al. 2018). Where such open energy data should be structured with well-defined standards linked by matching meta-data made available in standard formats or through open Representational State Transfer (REST) Application Programming Interface (API) (Lloret et al. 2016). Moreover, the license of such energy data should be explicitly stated if the data can be shared and freely utilized by third party applications. While, considering the privacy (private information) of prosumers by applying techniques of anonymization when needed (Nathali Silva, Khan, and Han 2017). Thus, data management of energy prosumption services in smart cities should include collecting, storage, analysis, and visualization of energy produced, consumed, available to be traded in the smart grid by employing different customized big data and relational database tools (He et al. 2018).

Additionally, energy devices generate enormous heterogenous data, which evolve from gigabytes to exabytes (He et al. 2018). Although several architectures have been proposed by prior studies (Bedogni et al., 2013; Lloret et al. 2016; Nathali Silva, Khan, and Han 2017; Ta-Shma et al. 2017). There are fewer studies that have successfully integrated big data to support energy prosumption to provide autonomous value-added services such as energy trading, use of collected processed data in green energy marketing strategies to predict energy needs forecasting, etc. Where prosumers can predict and monitor their electricity prosumption through the use of EA approach in smart city domain. Respectively, there is need for an architecture to orchestrate the efficient management of various structured, unstructured, and semi-structured energy data in supporting the sharing of energy data (Nathali Silva, Khan, and Han 2017).

Besides, an architecture is required to be able to process both real-time energy data from metering devices as well as historical energy data to ensure that aggregated data are updated in a scalable and incremental manner as the energy data are continuously generated (Bedogni et al. 2013). Similarly, Schleicher et al. (2016) recommended that the architecture should be flexible to extend its capacity of data processing to provide procedure to fully resolve the complex security compliance, regulations, restrictions, and ownership that arise. Likewise, Costa and Santos (2016) stated that such approach should facilitate municipality administrators, government and energy providers to efficiently manage energy consumption of cities.

2.5. Related works

A few studies have been published that explored how big data can be integrated into an architecture to support energy production and/or consumption in smart cities. This section reviews the selected studies as seen in Table 2 in addressing the third research question.

The review studies in Table 3 reveal that there is lack of a study that investigated energy prosumption (energy consumption, production, trading), big data, and further employ any of the reviewed EA frameworks in their study to improve energy sustainability. Hence, there is need for such studies to present the requirements and concepts involved in employing big data to EA toward improving energy prosumption in smart cities.

3. Methodology for energy prosumption in municipalities

As previously stated, prosumption refers to when energy consumers such as households, communities, organizations, businesses, and other agents dynamically manage their own production and usage of energy by relying on smart meters and solar PV panels or other renewable energy sources to produce electricity. Prosumption presents two stimulating

Table 2. Prior studies on big data, architecture and/or energy prosumption.

Authors & Contribution	Purpose	Layers/Components	Methods	Context
Ahuja and Khosla (2019) developed a framework for smart energy metering to improve consumers involvement to improve efficiency and conserve energy.	Motivated on employing data analytic technologies and data approaches for smart energy metering.	Smart energy meters, heterogenous wireless communication networks, cloud computing, data servers, gamification approach, behavioral interventions, and improved energy efficiency.	Used data analytic tools and integrated data analyzing approaches are used on smart energy metering.	Involved big data analytics for energy efficiency and conservation.
Hwang et al. (2017) proposed an energy prosumer business-based model facilitated by blockchain system to improve safety and transparency.	Supported several sources of energy to be linked to consumers and producers in enhancing energy efficiency by assessing energy use pattern.	Server, Big data, cloud computing, IoT, blockchain system, energy prosumer-business service layer, and user.	Carried out experiment with big data and Internet of Things (IoT) technologies.	Renewable energy production from solar.
Kanchev et al. (2011) designed energy operational and management planning of a PV-based active generator linked to microgrid in smart grid.	Aimed to deploy a determinist energy management system for a microgrid, with advanced PV generators integrated with gas microturbine and storage units.	Loads, communication bus, aggregator, microgrid central, energy management system, prosumers, and distributed system operator.	Employed experimental case study prototype to measure PV energy load management, forecasting, and prediction.	Energy production from PV based generators in domestic areas.
Zuccalà and Verga (2017) presented a digital ecosystem architectural reference model for achieving an energy-oriented digital sharing city.	Focused on promoting energy oriented smart cities via urban sharing ecosystems.	Services, management process (technical management board), evolution process (governance board), central infrastructural components, and end user applications.	Conceptual, no experiment was carried out.	Involves data sharing for energy services.
Costa and Santos (2016) utilized NoSQL databases to manage big data within a smart city context to orchestrate traditional energy bill, via mobile and web applications.	Aimed to research on re-inventing energy bill in smart cities based on NoSQL technology.	Big data analytics, data integration, big data storage, applications, and smart city (citizens, government, and energy providers).	Conceptual, no experiment was carried out.	Mostly related to managing of electricity bill based on big data.
Ma et al. (2016) designed a multi-party energy management framework for PV prosumers and internal price demand response.	Focuses on the energy management of photovoltaic prosumers and microgrids.	Micro-grid, prosumers, micro-turbine, EMS, and power grid.	Adopted a game theoretical method based on heuristic algorithm.	Energy production from PV linked to micro grid.
Kotilainen et al. (2016) developed a prosumer oriented digital energy ecosystem framework.	Intended to attain a decentralized electricity creation using renewable energy sources based on complex network of new and incumbent actors, processes and business models.	Macro, energy market, innovation ecosystem, prosumer, policy, and innovation.	Conceptual, no experiment was carried out.	Relates mostly to PV generated energy markets as socio-technical change.
Vergados et al. (2016) examined how to achieve prosumer grouping into virtual microgrids for cost decrease for trading renewable energy markets.	Intended at improving the orchestrating of energy prosumers into virtual clusters, to enhance participate in energy market to lessen total energy cost.	Virtual Micro Grid Decision Support System (DSS), DSS algorithms, energy negotiation module, data base, APIs, cloud engine, and DSS acquisition module.	Employed experiment on real dataset of 33 prosumers situated in Greece tested on clustering algorithms for performance evaluation.	Assessed how energy cost reduction can be achieved with prosumers from renewable energy source.

(*Continued*)

Table 2. (Continued).

Authors & Contribution	Purpose	Layers/Components	Methods	Context
Mustafa et al. (2014) designed a roaming EV charging and billing approach grounded on an anonymous multi-user based protocol.	Motivated at implementing a secure roaming EV charging protocol that aids preserve users' privacy.	Home (appliances, smart meters, and smart card), EV, user, suppliers, renewable energy source, EV supply equipment, and trusted authority.	Deployed experiment to evaluate the formal security verification for EV charging and billing.	Involved energy production and consumption in homes and EV marketplace.
Grijalva and Tariq (2011) suggested a prosumer oriented smart grid architecture that facilitates sustainable electricity.	Focused on attaining a prosumer-based service-centered architecture to improve scalable and flexible and facilitated a flat market paradigm across the energy industry.	Devices, local control, system control, and market layers.	Conceptual, no experiment was carried out.	Energy prosumption from residential areas.
Karnouskos, Da Silva, and Ilic (2012) developed an approach to improve energy services for smart grid in smart city.	Focused to improve the smart grid by capturing several electricity services based on the common needs of all stakeholders that can be made available to all consumers.	Smart grid devices, operators, prosumer, public services, and enterprise integration and energy management system.	Employed REST for PUT/GET/DELETE/POST methods deployed in java over business data stored in MySQL database.	Mostly concerned about energy trading, optimization, prediction, and monitoring.
Rathnayaka, Potdar, and Ou (2012) reviewed the characteristics of handling prosumers in smart grid.	Aimed to examine the socio-technical aspect of prosumer management in smart grid.	Smart infrastructure, bidirectional communication, intelligent data processing and control, protection, environment interaction, and prosumer management.	Conceptual, no experiment was carried out.	Mostly related to energy sharing comprising virtual power plant, microgrids and V2 G technology.
Rathnayaka, Potdar, and Ou (2012) suggested a goal-based prosumer community groups for smart grid.	Deployed a decentralized virtual micro grid that supports prosumers to intelligently accomplish certain communications and decision-making tasks.	Prosumer community group, smart storage, community gateway, community management platform, smart grid system management, and utility grid.	Conceptual, no experiment was carried out.	Entails prosumer's energy and behavior data for prosumer assessment and ranking scheme.
Vogt et al. (2010) suggested how market-centric prosumer involvement can be improved in the smart grid.	Aimed to present an architecture for Energy Management System (EMS) and explored the capability of offices to contribute to the smart grid.	Physical infrastructure, monitoring (reporting/visualization), regional energy marketplace.	Carried out experiment to improve energy optimization.	Comprised of EV, solar PV, and wind energy generation.

Table 3. Stakeholders involved in energy prosumer market adopted from (Karnouskos et al. 2011).

Stakeholders	Description
Energy retailer	The energy retailer sells energy in the neighborhood marketplaces. Thus, energy retailer aims to provide a longer-term contract to the citizens, while managing the associated risk involved in purchasing electricity at the local market and offers extra load that consumers might require. Besides, the energy retailer provides opportunity for energy consumers to get a forecast of the future energy information via transactions trends in the market. This may support toward better strategic planning when networking with the national level markets.
Distribution energy operators	In a smart city neighborhood, energy is supplied by local distribution energy operators (DEO) who manage energy transmission. The local DEO oversee maintenance of energy infrastructure and electricity distribution to consumers. Also, DEO interacts with the energy marketplace to obtain information regarding future energy consumption within the city, which is used to assess the available energy to the existing households. Moreover, the DSO provides value added energy services such as real time data on energy usage, customer usage prediction, and data on energy prices transactions over the energy marketplace.
Residential prosumer	The residential prosumer is the citizen that consumes and produces energy. The residential prosumer is a key player in the energy marketplace and can benefits from flexible energy tariffs and possible optimization of energy usage. The prosumer adjusts his/her energy usage/production based on dynamic market prices for the electricity that is produces and sold.

(*Continued*)

Table 3. (Continued).

Stakeholders	Description
Commercial prosumers	Commercial prosumers include energy dealers of energy production or consumption such as shopping centers, industrial buildings, wind turbine farms, public infrastructure, EV fleets, etc. The commercial prosumers may gain from lower energy prices, by rescheduling/controlling energy usage, but more significantly commercial prosumers could trade this flexibility to the energy market which generate new means of revenue.
Market operator and regulators	The market operator supports energy market operations such as prosumer identity management, electricity billing, transaction security, clearing, etc. Moreover, market operator aids prosumer interactions with other stakeholders in the smart grid.
Regulators	The regulators are involved in regulating energy prices in a community district. This helps in creating a balance in demand and supply of energy.
Service Provider	Service provider orchestrates real-time smart energy metering, energy trading management, energy information exchange etc. in proving new innovative applications and value added services to other stakeholders. Service providers support third party service providers to find marketable areas and provides new energy related services that can be traded on the energy marketplace. They also provide services that can be combined with the existing marketplace services. Such service could be data analytics for energy prediction to provide useful information to residential prosumers in making decision for buying/selling electricity in the energy marketplace.

paths for a low-carbon energy system (Liu et al., 2017). The first path is geared toward the deployment of several self-sufficient and off-grid citizens or agents that autonomously manage their energy consumption and production (Zafar et al., 2014). This roadmap is mostly attainable for citizens that economically, technically, and geographically can deploy enough energy and storage renewable capacity integrated to smart home or building management systems (Parag and Sovacool 2016). The second area entails prosumers being active providers of energy services to the smart grid and can supplement or may even participate with traditional energy and utilities companies. Prosumption through either path, can enable citizens to save cost while contributing to broader societal benefits by diversifying energy supply and reducing greenhouse gas emissions (Haarstad and Wathne 2019).

Correspondingly, Figure 7 shows the stakeholders and energy providers that work with prosumers in operating a decentralized electricity grid in restructuring the energy markets such that prosumers can maximize the societal gains while improving quality of life.

Based on Figure 7 each of the functions of the actors in the energy prosumer market are described in Table 3 below;

Table 3 depicts the stakeholders involved in energy prosumer market, where this study considers energy trading between prosumers in smart grid. Where prosumers can opt to connect to an energy service provider and purchase electricity or disconnect and rely on generated energy to meet their energy demand. Furthermore, prosumers may trade, buy or borrow energy from other prosumers in the same neighborhood when their energy supply cannot meet their current demand as seen in Figure 8. They may also lend or sell surplus electricity to other consumers, although citizens in smart city buy electricity from energy service provider in the national market. Hence, there is need for an architecture that aims to create a structure where consumers' energy data can be viewed and where energy produced within the neighborhood can also be viewed locally ensuring a more resourceful management of energy prosumption in the neighborhood. Hence, this study develops an architecture (see Figure 9) which provides a cross-layer and open data flow among the prosumers and stakeholders involved for better energy management in achieving better energy prosumption.

4. Case study (Evaluation of developed architecture)

This study develops an architecture based on TOGAF as described in Section 2.1.1, for management energy prosumption data of EV and residential buildings. The developed architecture depicts how EA can be employed to facilitate energy prosumption operations in smart cities. Respectively, the architecture is evaluated using data from the literature to provide evidence on how the architecture facilitates interoperable real-time, online, and historical data in achieving energy sustainability from PV solar as seen in Figure 9.

Figure 9 shows findings from a case study on how data from heterogenous sources are managed in smart city to support energy prosumption. The architecture comprises of seven layers (context, service, business, application and data processing, data space, technology, and physical infrastructure) where the business, application and data processing, data space, technology layers were derived originally from TOGAF and context, service, and physical infrastructure were incorporated to extend TOGAF from enterprise domain to smart city domain to explore how renewable energy prosumption services can be achieved via application of big data. Thus, each of the layers in Figure 9 is discussed below;

4.1. Context layer

This layer is an abstract representation of the main feature or capability to be provided (Abu-Matar and Davies 2017). In the context of this study the context layer comprises of the motivations and requirements. Thus, it involves the Key Performance

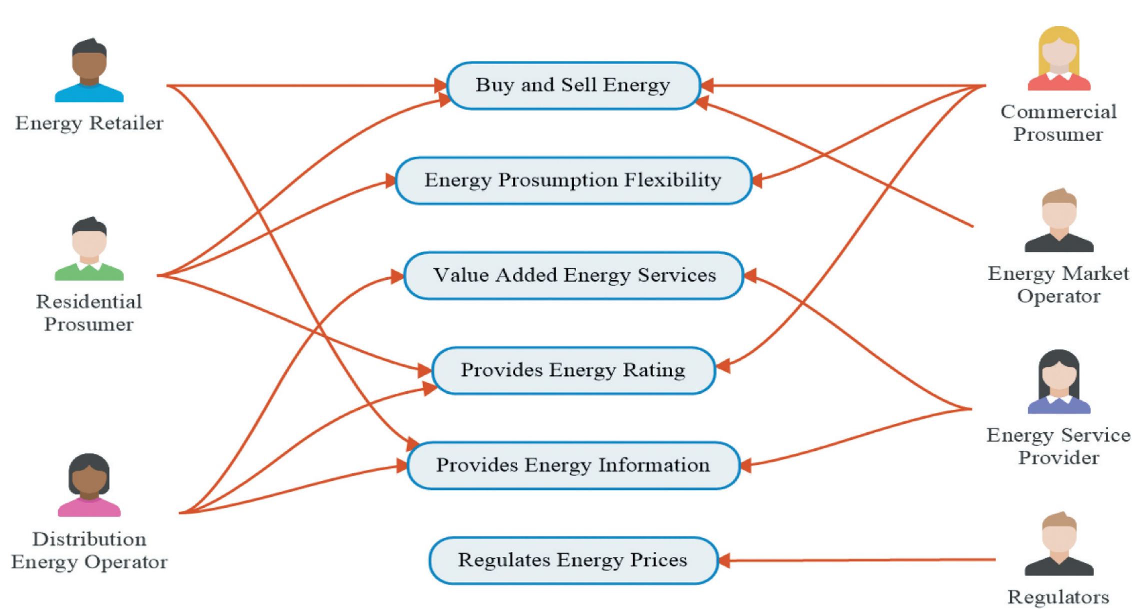

Figure 7. Overview of energy prosumer market adopted from (Karnouskos et al. 2011).

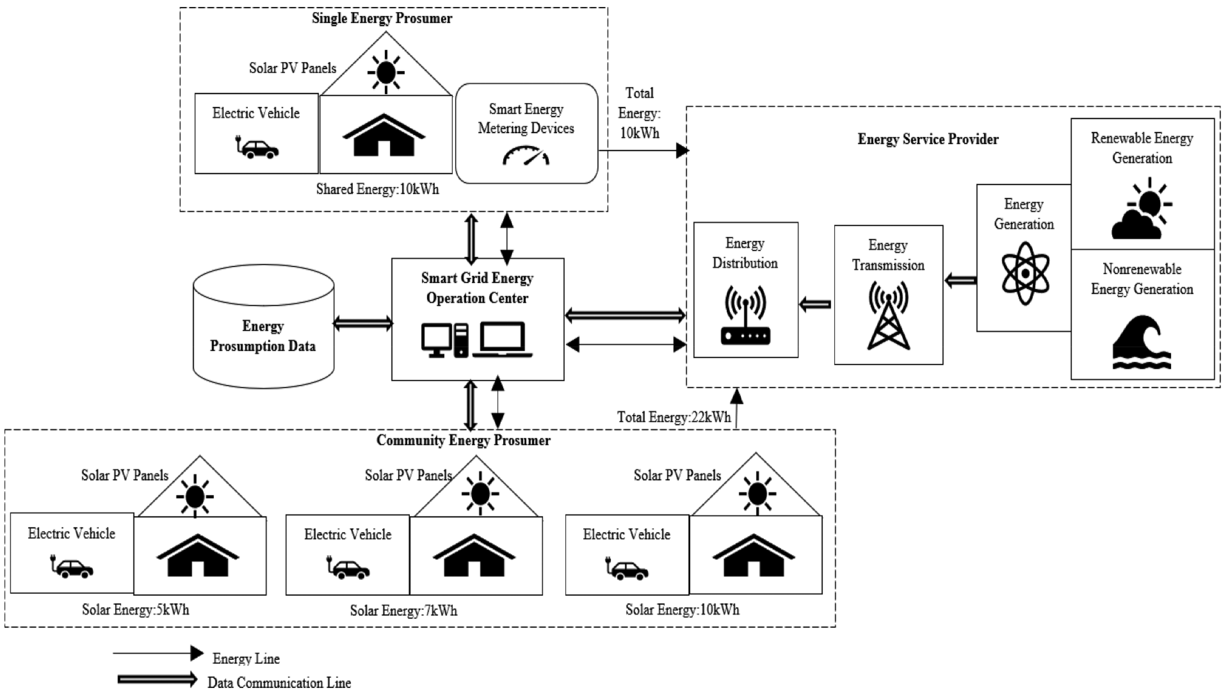

Figure 8. Prosumers community integration in smart city.

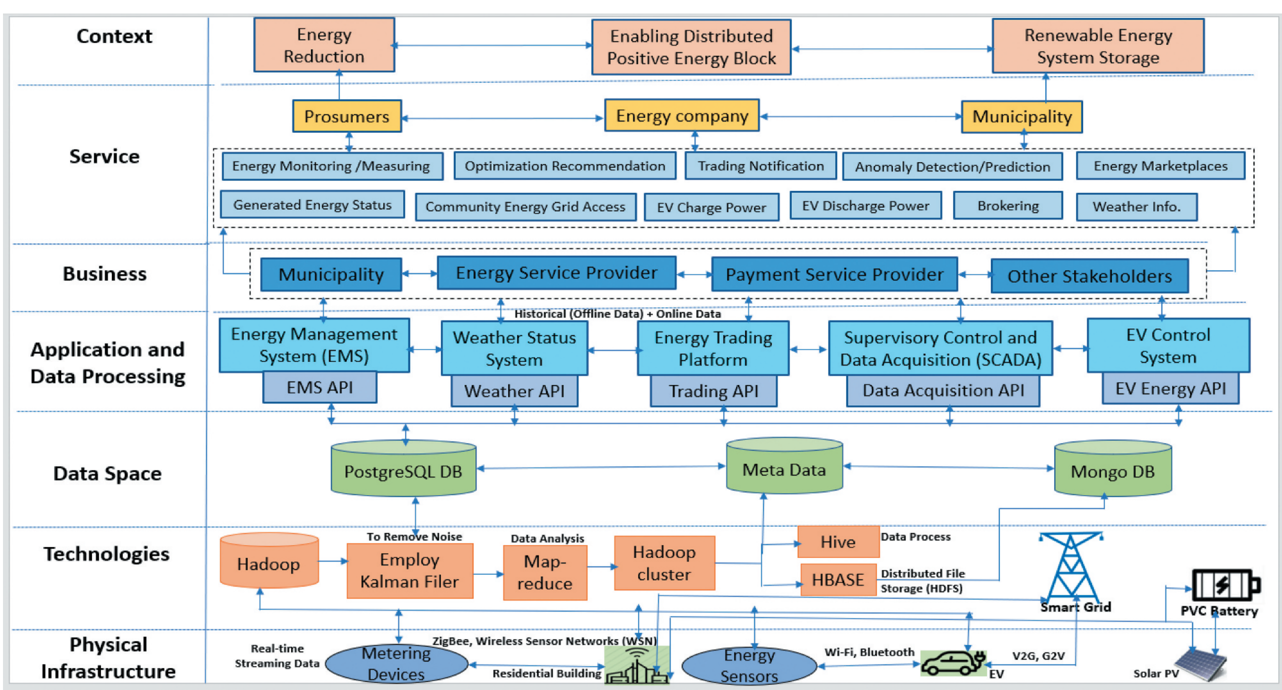

Figure 9. Proposed smart city data architecture for energy prosumption.

Indicators (KPI) to be achieved in the energy prosumption of EVs and residential buildings facilitated by big data and enterprise architecture. The context layer outlines the aggregated expectations of all stakeholders involved in the energy prosumption operation in smart city. Findings from Figure reveal that the context layer comprises of energy reduction, enabling distributed positive energy block, and achieving a renewable energy system storage.

4.2. *Service layer*

This layer refers to activities required to accomplish business processes (Barbosa et al. 2016). Accordingly, researchers such as Winter and Fischer (2006); Abu-Matar and Davies (2017) maintained that service layer is the most critical layer in as it provides a context for communication between citizens and enterprises. Also, it relates to adoption of digital activities within smart communities. Since this layer specifies precise services provided by applications in smart cities (Barbosa et al. 2016). Findings from the literature suggest that service layer comprises of trusted entities such as municipalities, prosumers, and energy company which offers energy related services (Moreno et al. 2016). Hence, the service layer is mostly operated by energy service provider and it involves the consumers and producers of energy service. Service layer facilitates the deployment of e-mobility for EV and energy management applications in residential areas (Abu-Matar and Davies 2017). Service layer also involves smart city operations that supports businesses to deploy smart cities applications such as energy monitoring/measuring, optimization recommendation, trading notification, etc. (Moreno et al. 2016).

4.3. Business layer

Business layer specifies the processes enterprises employs to meet their goals (Sessions 2007). Business layer involves several types of stakeholders such as policy makers, citizens, businesses, etc. This layer involves businesses' vision, mission, goals, and strategy and how each enterprise will meet its aligned goals as relates to sustainable energy prosumption (Cox et al. 2016). Thus, this layer involves the enterprises that collaborate to provide energy related services to support energy prosumption processes (Minoli 2008). The business layer aligns each enterprise operating approach, objectives, and strategies with IT (Oracle 2009). Besides, this layer models the collaborative flow of interdependent enterprise tasks executed (Abu-Matar and Davies 2017). Hence, the business layer provides the governance and operational capabilities needed to support energy prosumption in smart cities (Cox et al. 2016).

4.4. Application and data processing layer

This layer mainly defines the types of applications that are required to support energy prosumption (Cox et al. 2016). The applications layers also describe how available applications share data with each other in providing the functionality required to deploy prosumption services (Abu-Matar and Davies 2017; Sessions 2007). Moreover, application layer involves how open data is transformed into information and utilized by stakeholder for various energy services (Schieferdecker et al. 2017). This layer deploys different web services such as Extensible Markup Language (XML), Simple Object Access Protocol (SOAP), Representational State Transfer (REST) via Application Programming Interface (APIs) (Gaur et al. 2015). Findings from the literature indicates that this layer provides a set of APIs to support energy management, weather status, energy trading, data acquisition, EV energy management, etc. In addition, the application layer is linked to open real-time, online, and historical data that is used to make decision regarding energy trading by prosumers (Zygiaris 2013). The application layer includes software applications that utilize available data accessed via the data space layer to facilitate prosumption services and further supports third party developers to make data availability via standardized APIs used by applications (Vilajosana et al. 2013).

4.5. Data space layer

Data space is the brain of the architecture and it outlines the types and sources of data needed to facilitate energy prosumption services in smart cities (Cox et al. 2016). This layer describes how the city data repository is organized and accessed (Sessions 2007). It identifies where significant blocks of information, such as prosumers record, are retained and how they can be accessed (Minoli 2008). Moreover, this layer executes a variety of data analyzing, manipulating, organizing, storing, and management of data (Silva, Khan, and Han 2018). Hence, the data space is an open data repository that provides meta data, real-time\online data and historical data to enable data interoperability, offering inventive opportunities for open web services via open and linked data. Data space offers a well-defined APIs that provide data to improve energy prosumption in smart cities (Vilajosana et al. 2013; Zygiaris 2013).

Furthermore, data layer stores processed energy data from metering devices, energy sensors, etc. in MongoDB database as suggested by Zabasta et al. (2018). MongoDB is opted as a good choice for storing JSON encoded data as it internally retains data in a well-organized binary JSON format (BSON) (Zabasta et al. 2018). This layer also stores Metadata, which refers to the tags or descriptors that classify a document, dataset, data model, or data source (Tcholtchev et al., 2017). The metadata information is automatically generated by data processing system based on a standard of DataCite Metadata Schema and serves as a link to isolated data and aids data fusion in smart cities (Liu et al. 2017).

4.6. Technology layer

The technology layer describes the software and hardware infrastructure that supports data and applications (Minoli 2008; Sessions 2007). Hence, the technology layer describes how the infrastructure related to the business, application, and data layers are organized (Oracle 2009; Winter and Fischer 2006). It provides a technical reference layer that align the physical infrastructure such as energy battery, energy devices (smart grid) and big data tools and solution (HFDS, hive, HBASE, etc.) (Cox et al. 2016). According to Gaur et al. (2015) the technology layer aims to convert collected heterogeneous data into a common format such as Resource Description Framework (RDF). Figure 10 depicts the energy data processing and management for energy prosumption in technology layer

As seen in Figure 10, heterogenous energy data are processed based on a defined threshold value for each domestic energy consumption. Furthermore, raw energy data are generated from EV and residential appliances at ever-increasing speed. Hence, there is a need for these energy data to be collected and stored without any loss. Thus, an infrastructure that collects and stores energy data at a low cost is required. Hence, this study opted to use both MongoDB Not Only SQL Database (NoSQL) and Hadoop Distributed File System (HDFS). Thus, data filtration technique is employed by the fusion method to assess if any value exceeds the threshold. Next, MapReduce technique is utilized for energy data analysis, manipulation and storage in HDFS, HIVE, and HBASE.

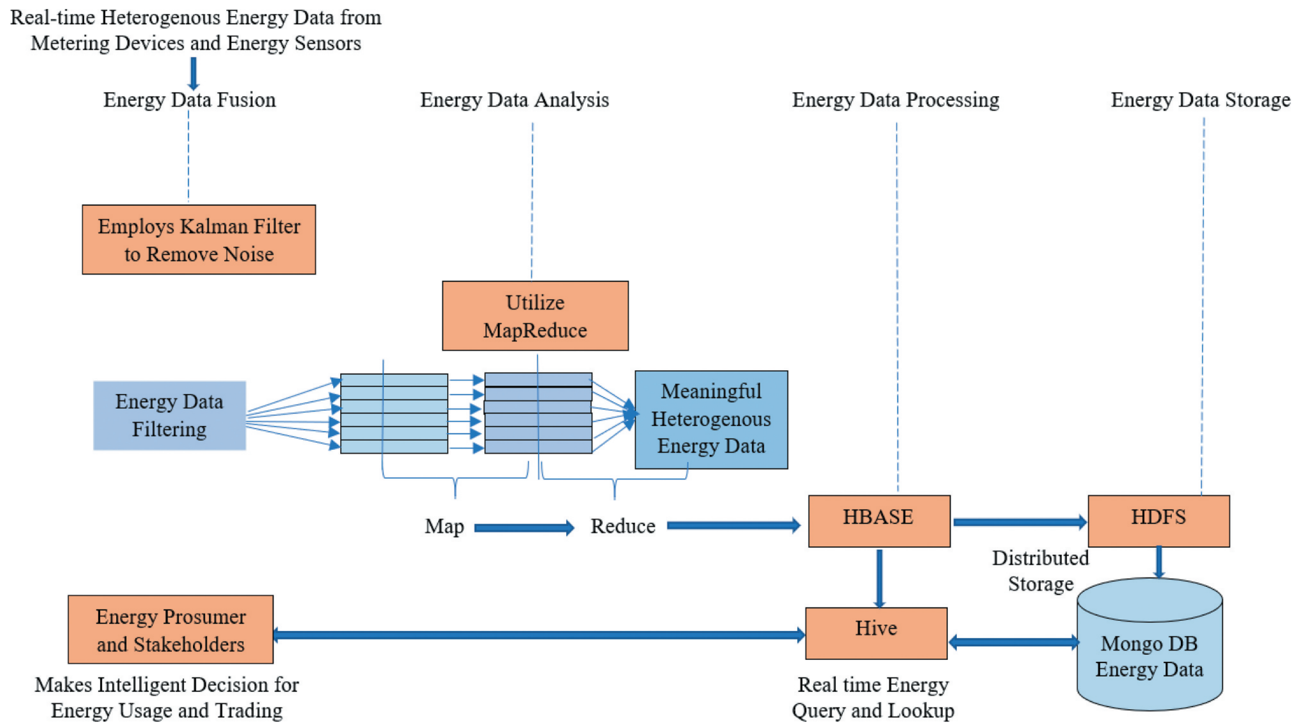

Figure 10. Energy data processing and management for energy prosumption.

Particularly, energy data are stored in their generated raw form, until they are queried using HIVE. In the architecture (see Figure 9), enormous raw energy data are collected and stored in Hadoop and later filtered using Kalman Filter (KF) to acquire value from the data after which Hadoop MapReduce further process the data.

Furthermore, the fusion technique is employed to improve data processing proficiency by implementing data filtration. Thus, KF is employed to perform data filtration as seen in Figures 9 and 10, where KF is an optimal estimator that removes noise (meaning less) data from the generated energy data. MapReduce is deployed in two steps. The first step involves the mapping process where sets of filtered energy data are transformed into another set of data. In the second step, the Reduce process combines the changed energy data transformed in mapping process and the data are presented into a set of values, which are reduced in amount. As seen from Figures 9 and 10 the energy related data processing and analysis utilizes various techniques, which comprise of HDFS, HIVE, and HBASE. The energy data storage demand for prosumption operation is supported by HDFS, which is the main storage of Hadoop.

Since, HDFS storage is distributed, it supplements the MapReduce processing on smaller subsets of larger data cluster and saves in the non-relational database such as Mongo database. Additionally, HDFS improves the scalability demand of the heterogenous energy data processing. Hence, HDFS enables real-time read and write functionality over the entire cluster to enhance autonomous decision-making of prosumers and other stakeholders. Moreover, HBASE is used to improve processing speed on Hadoop as it provides server-side programming, real-time lookups, and in-memory caching. Further, it improves fault tolerance and usability. Likewise, HIVE is included to facilitate prosumers in managing and querying over large amount of energy data that is saved on the Hadoop cluster. Since, SQL cannot be utilized to query on HIVE this study utilizes HiveQL to query energy data on Hadoop cluster to provide intelligent decisions in supporting prosumption operations.

4.7. Physical infrastructure layer

This layer includes data generation from energy devices such as EV, charging stations, domestic buildings, PV solar panels, metering devices, energy sensors, etc. (Silva, Khan, and Han 2018). This layer generates real-time heterogeneous data collected in aggregate from the energy devices that is transferred to the technology layer for further processing (Gaur et al. 2015). Hence, this layer comprises of all the physical facilities, which are required to gather data from equipment needed for prosumption services (Schieferdecker et al. 2017). These generated data sources include data streams with high degree of velocity and variety that comprises of JavaScript object notation (JSON), Comma-separated values (CSV), Extensible Markup Language (XML), TXT File format, etc. (Costa and Santos 2016). Furthermore, data generated from the energy devices can be either unstructured or semi-structured, where the semi-structured data are encoded as JSON adhering to REST protocol (Silva, Khan, and Han 2018). Moreover, communication protocols such as Bluetooth, Zigbee, Near Field Communication (NFC), Machine-to-machine (M2 M), Zwave, Radio Frequency Identification (RFID) sensors, actuators, and global positioning system (GPS) terminals, wi-fi or Bluetooth are utilized for communication among the physical energy devices (Zygiaris 2013). Likewise, 3 G, 4 G LTE, 5 G, and low power -wide area networks (LP-WAN) are used in this layer (Silva, Khan, and Han 2018).

5. Requirements and future directions

Energy is a necessary element required to perform different type of operation. Energy can be generated either from renewable source (solar, geo-thermal, and wind) or nonrenewable source (fossil fuel). The benefits of energy prosumption in smart cities are important to the development of municipalities. Therefore, further studies on cost resourceful design and implementation is extremely desired to promote energy prosumption around the world. Therefore, increasing renewable energy sources in municipalities is another compulsory area that promotes energy sustainability of city operations and also improves insufficiency of nonrenewable energy sources. Additionally, metering devices and energy sensors in EVs and residential building in smart cities generate huge amount of heterogenous data that necessitate large data storages. Due to big data generation, traditional data processing techniques and methods have become outdated for use in analyzing energy data. Accordingly, it is important to integrate big data analytics tools for energy prosumption in smart city environments to address these challenges analogous to prior studies (Karnouskos, Da Silva, and Ilic 2012; Costa and Santos 2016; Hwang et al., 2017; Ahuja and Khosla, 2019). Nevertheless, most of the studies are not based on real world cases. Hence, there is a need to utilize open real-time, online, and historical data from energy devices and EV to deploy prosumption operations in actual real will be a fruitful research opportunity for future studies.

In addition, one of the main challenges faced in implementing an energy marketplace in smart city relate to privacy of prosumers data. Safeguarding sensitive data and implementing security of prosumers sensitive data is required in smart city environment. Thus, if prosumers security is not guaranteed they may decline to contribute which will negatively impact the reliability of smart grid operations. Therefore, it is required to deploy a common security protocol for securing EV and residential buildings connected to the smart grid. Moreover, the exploitation of heterogeneous energy devices deployed to facilitate prosumption operations is another crucial research area. This is because different components such as for EV charging and charging station connect to provide reliable and timely energy related services. Thus, addressing interoperability and aggregation issues among prosumption devices and applications is requires further investigation. Lastly, there is need to improve technologies deployed for effective generation, transmission and storage of electricity as well as data in smart grid to reduce cost incurred in maintaining the operation of the smart grid.

6. Discussion and implications

6.1. Discussion

This study conducted an extensive review and developed an architecture to promote energy prosumption operations in municipalities. The architecture was developed by extending TOGAF. Findings from the comparative study (see Table 1) reveal that TOGAF provides appropriate layer integration and repository integration in relation to other EAs. According to Cameron and McMillan (2013) TOGAF was the most widely used standard with about 82.2 percentage, as compared to Zachman framework with 52.7 percentage, Gartner with 26 percentage, FEAF with 21.2 percentage, and lastly DoDAF with 16.4 percentage. Moreover, TOGAF is more focus on IT development and provide appropriate alignment between IT and business. The developed architecture aims to share energy data and improve energy services to prosumers and stakeholders via open real-time, online, and historical data to improve the overall efficiency of energy and creating value added services. Similarly, the architecture exposes energy data as web services via APIs to provide accessible information to prosumers, energy retailers, distributors etc. to help in optimizing electricity utilization in municipality. Furthermore, Hadoop using MapReduce big data tool is employed to process analyzed energy data to support intelligent decision making in municipalities. Also, the architecture facilitates analysis of energy data by exploiting real-time, online, and historical data energy data to improve energy prosumption.

6.2. Implications for policy and practice

This study provides a general overview of energy prosumption in municipalities and develops an architecture to be used as a reference model to provide further insight on how to deploy a self-sustaining energy city. Although, smart city architectures for energy prosumption have been developed by prior studies (Grijalva and Tariq 2011; Rathnayaka, Potdar, and Ou 2012; Kotilainen et al., 2017; Zuccalà and Verga 2017), they are mostly focused on the technical perspective and paid less attention to citizens aspect. Thus, it is imperative to include citizens to be a part of the smart city solution in improving the energy sustainability. Moreover, this study offers practical implication by providing a general view of the current deployment of smart grids for energy prosumption.

Respectively, the smart grid is an autonomous electricity transport network, which manages the bidirectional energy and data flows among generation plants, distribution, prosumers, and applications. The developed architecture can be adopted as a starting point for conceptualizing the generation and achieving of a positive energy community in cities by offering a framework to stimulate value-added generation from data generated from EV, domestic appliances, metering devices, and energy sensors. Besides, the architecture provides economic benefits to prosumers by creating flexibility energy trading and decrease CO2 emissions, by increasing exploitation of renewable energy from solar PV. In summary, findings from this study provides an energy trading market that increase the consumption of renewable energy, and decrease costs of energy generation, energy purchase, and energy storage.

7. Conclusion

Prosumers are new actors in the smart grid that produce, utilize, store, share, and sell energy with other consumers in the smart grid. They play an important role in the energy value chain by contributing toward innovation, value creation, and enabling energy flexibility. Prosumer communities in smart cities help enable an effective and clean energy sharing service. The role of prosumers in the energy markets can help manage demand response, maximize commercial and residential energy productivity efforts, and create a ubiquitous distributed sustainable energy for the society. Deploying an energy marketplace for neighborhood district level or community block within smart cities may be a prospective method toward achieving effective distribution of energy in the local energy market in managing energy demand.

Currently, little work has been carried out that explores sustainable energy prosumption operation in relation to EVs, residential energy consumption, big data and layer architecture in smart city domain. Accordingly, grounded by TOGAF standard this study proposes a smart city big data architecture to manage energy prosumption services of residential building and EV in municipalities. However, the developed architecture is mainly concerned with renewable energy generation from solar PV only and does address other smart city services. Besides, no dataset was utilized to test the applicability of the architecture. Thus, future works will involve validating the architecture by using primary data from an energy company to empirically test the applicability of the proposed architecture. This will help to provide insight on the practicability of the architecture and further validate each layers of the architecture.

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