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API Deployment for Big Data Management towards Sustainable Energy Prosumption in Smart Cities-A Layered Architecture Perspective

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Abstract

Smart city has emerged as a universal term for the pervasive utilization of Information and Communication Technologies (ICTs) deployed to provide value-added services to citizens based on data generated from sectors such as energy, mobility, etc. However, current approaches are faced with interoperability as a challenging issue in processing big-data. Therefore, this study explores the role of Application Programming Interfaces (APIs) for managing real-time, online, and historical energy data in the context of residential buildings and Electric Vehicles (EVs). Moreover, a layered architecture that employs APIs in big data is developed for district energy management towards providing energy information intelligence and support decision making on energy sustainability in facilitating prosumption operations. Practically, the layered architecture collects energy data and provides data to prosumers who are citizens that produce, consume, share, and sell energy generated from renewable sources such as solar and wind to better improve energy prosumption in smart grid.

Keywords: Sustainable energy prosumption; Energy district; Electric vehicles; API integration; Big data architecture; Smart grid.

1. Introduction

It is predicted that by 2050, 70 % of the total world's population will reside in cities. Thus, these cities need to be smart to address sustainability issues related to increased energy consumption (Chang and Lo, 2016). A smart city is an integrated ecosystem embodied by the prevalent use of Information and Communications Technologies (ICTs), aiming to make cities more sustainable (Jnr et al., 2018). Accordingly, to promote sustainable development in cities, it is important to efficiently manage data generated between stakeholders, applications, and physical devices (Sánchez et al., 2013). Currently, most cities utilize conventional centralized energy systems that relies mainly on large scale power plants based on non-renewable energy sources such as coal, natural gas, petroleum, and nuclear, etc. (Michas et al., 2019), which produce Green House Gas (GHG) emissions that results to global warming and climate changes (Liu et al., 2017). Therefore, most governments and scientists around the world are centered on generating electricity through renewable energy sources such as solar, wind, water, etc. (Zafar et al., 2018). Citizens are also being encouraged to be part of the energy value network by generating energy from renewable sources and to store surplus energy for future consumption or trade it back to the smart grid which facilitate bidirectional information and energy flow (Ma et al., 2016). Thus, the smart grid promotes economic sustainability by

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motivating prosumer to not only produce green energy for usage but also shares or sell the excess with other citizens within the same district or utility grid (Kotilainen et al., 2017).

Furthermore, smart cities entail the plethora generation of heterogenous data about various services in smart cities (Schleicher et al., 2017), such as energy prosumption which involves a “prosumer” who is an energy user that produces renewable energy in its domestic environment such as rooftop solar Photovoltaic (PV) systems wind turbines, and micro hydro power (Parag and Sovacool, 2016). Therefore, the efficient management of colossal heterogenous volumes of energy data is challenging, especially since data is collected from energy devices (Vögler et al., 2016), deployed within community districts to monitor and manage energy distribution (Brundu et al., 2016). Although, energy prosumption foster environmental, societal and economic development, they are faced with structural and architectural energy data processing issues that must be resolved (Ahlers et al., 2019). One of which involves the vertical silos’ which hinders integration of data and due to lack of openness and interoperability of energy data which can be utilized to produce new value-added services to prosumers. Hence, there is need for interoperable approach to facilitate development of open ecosystems and unlock the commercial potential of data (Kubler et al., 2017). Respectively, there is need for a dynamic and open approach that aids the seamless interaction and exchanged of data that provide a medium to expose and access data in an efficient, and predictable method (Nesi et al., 2016; Schleicher et al., 2017).

Accordingly, this study opted for Application Programming Interfaces (APIs) to be integrated as data adapters to establish connections for prosumers, stakeholders and real-time streaming, online and historical energy data in Comma-separated Values (CSV) files, spreadsheets, text file TXT, JavaScript Object Notation (JSON) format, etc. (Chaturvedi and Kolbe, 2018). However, there has been very little research that explore the role of API to provide access to energy data generated in district neighborhood towards promoting energy prosumption services. Hence, API is envisioned as a medium deployed to facilitate the accessibility of data regarding smart services such as energy and mobility in smart cities (Raetzsch et al. 2019). According to Borgogno and Colangelo (2019) API refers to a set of tools, protocols, and routines for developing software applications and they define how system components interconnect with each another to allow access to data sources. API aims to support the accessible of functions or data in a standardized method which can be utilized by different applications (Holley et al., 2014). Likewise, Borgogno and Colangelo (2019) stressed that APIs are integrated to strengthen interoperability among different systems and enable the exchange of data streams or datasets amongst data holders.

In terms of energy use in smart cities APIs are gateways to access the arising energy data-driven economy and have been acknowledged as main enabler of interoperability to ensure effective data sharing ecosystem (Badii et al., 2017), allowing citizens to thrive by extracting value from processed energy data and delivering customized services with momentous added value for energy consumers welfare (Borgogno and Colangelo, 2019). Besides, APIs ensure easy flow of data and enable a common interface for consumers to control and monitor heterogeneous sources of energy data generated from metering devices and energy sources in EVs and residential buildings. This helps municipalities to have an overview of energy distribution and consumption across the district towards designing efficient energy policies for citizens (Patti et al., 2014). Similarly, there is need for a layered architecture that allows both historical, online, and real-time data processing. This is because the rapid rise of data volumes exponentially reduces the performance of traditional data processing techniques (Silva et al., 2017).

Thus, a layered architecture has become a crucial demand for energy prosumption in smart city to collect variety of energy data consumption of residential buildings, usage of home appliances, EV charging from the grid (G2V) and discharging to the smart grid (V2G), etc. for creating value-added services for convenient of citizen (Takahashi et al., 2012). Similarly, researchers such as Silva et al. (2017) advocated for the need of data architecture capable of supporting autonomous decisions based on real-time energy data processing in smart city environment while ensuring system independency. The layered architecture will enhance the quality of service towards effective energy prosumption operations in smart cites. Therefore, this study aims to address the following research questions;

- What is the importance of API integration in big data management for energy prosumption?
- What are the existing categories of energy prosumption that be employed in smart cities?
- Which studies integrated API in smart city domain to improve smart city services?
- How can Message Queuing Telemetry Transport (MQTT) and Hypertext Transfer Protocol (HTTP) protocols facilitate energy prosumption in smart cities?
- How can RESTful API integration support big data management for energy prosumption in smart cities?

Therefore, this study develops a layered architecture embedded with RESTful APIs to facilitate energy data prosumption for EVs and residential buildings in smart cities. Compared to conventional data process approaches, the proposed approach can integrate APIs to extract and processes energy data more intelligently, while exploiting real-time, online and historical data processing speed, and improving decision-making of prosumers for energy trading. API deployment supports remote web accessibility of energy data and aids the collection and sharing of energy data autonomously that can be accessible and manageable via RESTful open web protocol or standards which allows cross-platform interoperability and communication. The rest of the study is organized as follow. Section 2 elaborates on literature review. The methodology is presented in Section 3. The discussion and implications of the study is given in Section 4. Finally, the conclusion of the paper is outlined in Section 5.

2. Literature Review

This Section provides a theoretical background on overview of smart grid, background of energy prosumption in smart city, big data management for energy prosumption, API for big data management, and reviews of related works.

2.1. Overview of Smart Grid

Energy demand across the world continues to increase and such demands were mostly supplied by non-renewable energy sources which results in greenhouse gas emissions, global warming, pollution, and other negative environmental impacts (Menniti et al., 2014; Jnr et al., 2019). Additionally, to manage increased energy demand, the smart grid concept was introduced which refers to an electric system that employs two-way bi-directional approach for information and energy in an integrated method across electricity generation, substations, distribution, transmission, and consumption to achieve a sustainable, reliable, clean, efficient, secure, safe, and resilient system to prosumers (Parag, 2015), as seen in Figure 1.

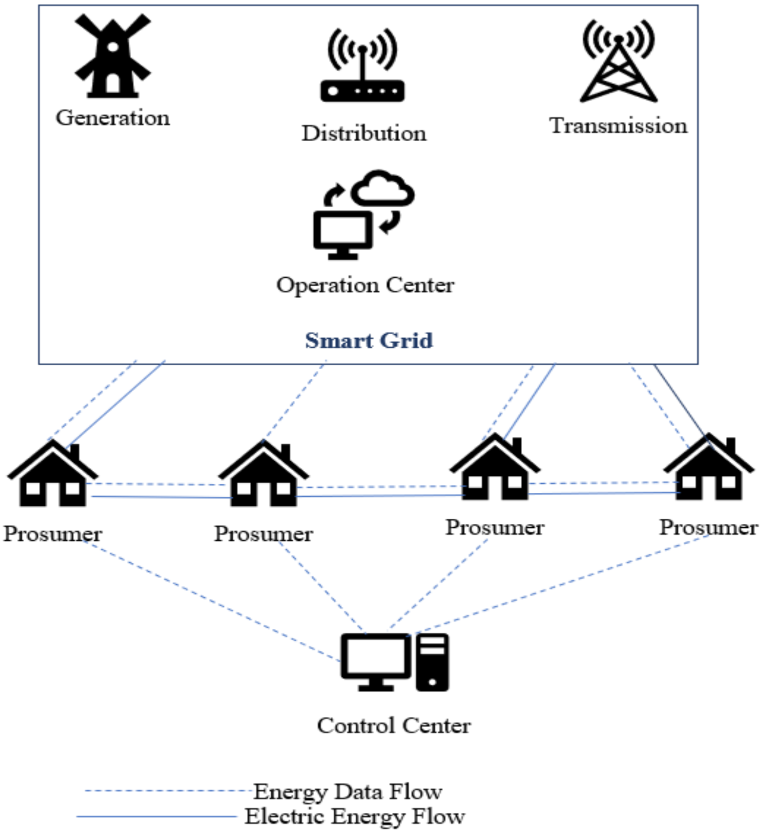

Figure 1 Overview of the smart grid

Figure 1 depicts an overview of the smart grid. Smart grids differ from conventional utility grids, in which consumers consumes energy from the energy utility supplier and are billed based on their usage (Rathnayaka et al., 2012). Moreover, the smart grid is based on five main components that facilitates continuous energy sharing and they include bidirectional communication, smart information and energy infrastructures, sustainable integration with prosumers, standards and legislation, and advanced management systems (Park et al., 2018). Accordingly, the smart grid competently integrates and manages the actions and behavior of consumers and generators connected to it to ensure economically competent, sustainable energy systems with negligible losses and improve security and quality of supply (Bellekom et al., 2016).

Smart grid involves deployment of physical devices from different vendors based on different policies and protocols integrated to achieve a mutual goal of attaining smart energy distribution and services. It provides a bi-directional human-to-machine platform that provides ubiquitous energy management and control which offers uniform control access to energy devices (Vernet et al., 2015). Thus, the smart grid encompasses application of Information Technology (IT) within the electricity grid to achieve a sustainable energy system (Bellekom et al., 2016). The operation of the smart grid mainly depends on energy data collected to better understand how energy is generated, distributed, and consumed (Parag, 2015). Hence, the control and monitoring of prosumption service is an important role for smart grid implementation. Besides, districts also play a vital role for smart grid operation, as they autonomously provide real-time energy via smart metering devices to manage their energy resources (Karnouskos et al., 2012).

2.2. Background of Energy Prosumption in Smart City

2.2.1. Energy Prosumption in Smart Grid

The rapid increase in demand of energy over the years have led to the growth of the energy sector where energy users in residential homes can now both produce and use energy. Also, surplus energy can be stored for future use or distributed to the smart grid for sharing with other energy consumers (Menniti et al., 2014). Due to this revolution, the smart grid created a pathway for "prosumers" who contribute to the electricity supply (Espe et al., 2018). Conventionally, stakeholders in the energy system are mainly consumers or producers of electricity. Currently, distributed renewable energy sources, demand response, and storage, facilitate consumers to generate and store energy (Grijalva and Tariq, 2011). Thus, prosumers are economically driven actors that consumes, produces, and stores energy, operates or maintains a small power grid and hence distributes electricity, and optimizes economic decisions concerning energy usage (Bellekom et al., 2016; Awad et al., 2018). Thus, energy prosumers may produce, store, share, or trade energy with other consumers in the grid (Takahashi et al., 2012), as seen in Figure 2.

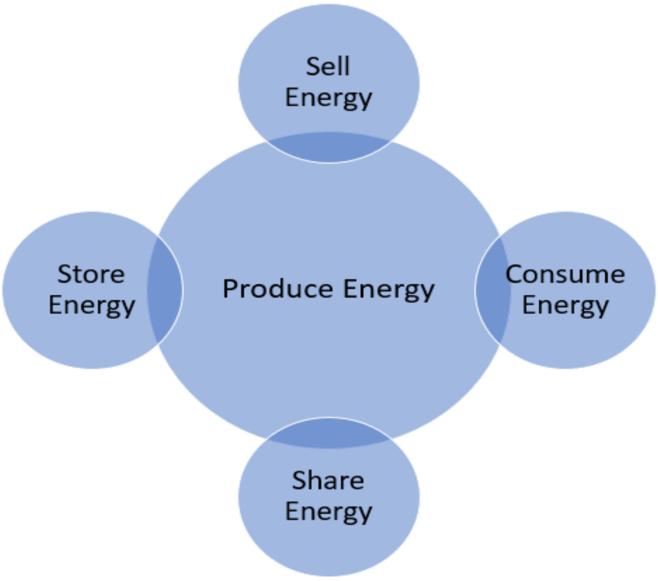

Figure 2 The role of a prosumer

Figure 2 depicts the role of a prosumer who physically, manages electricity production and participates in the local energy market to trade renewable energy produced in his/her domestic environment to nearby energy users in smart grid (Wi et al., 2013). Prosumers utilize smart meters during electricity production and deploy these energy devices with domestic energy management application, energy storage platforms, EVs, and Vehicle-to-Grid (V2G) systems to efficiently connect to the smart grid (Parag and Sovacool, 2016). As compared to energy consumers in conventional grids prosumers improve productivity in the energy system and enhances the operation of domestic appliances offering storage systems that help supplement electricity fluctuations to balance local energy demand and supply (Wentland, 2016). Additionally, prosumers can contribute in subsidizing distributed flexibility in the energy market by managing their electricity consumption and production schedules to achieve a decentralized storage system. This aids in improving prosumer roles towards contributing to the transformation from conventional to flexible energy systems in achieving sustainability energy sharing process (van der Burgt et al., 2015). Thus, prosumers create value to the developing energy system, as they play vital role in the energy value chain by contributing towards innovation, value creation and energy market flexibility (Nikolaidis et al., 2019).

Furthermore, prosumers groups aid sustainable and efficient energy sharing and trading system, where prosumers receive tariff for energy shared and may perhaps be given bonuses if they surpass the agreed energy delivery specified in their initial contract with the local energy contractors. Moreover, prosumption services supports development of technological and social innovations that substitute conventional energy services (Vernet et al., 2015). Prosumer markets act as a medium that changes citizens from being passive energy consumers to active contributors in the energy sector by being rewarded for supplied energy the same way district energy companies are being paid. Moreover, prosumers can choose which electricity services they intent to use allowing energy market flexibility in managing energy demand (Rathnayaka et al., 2012). This increased flexibility creates opportunities for prosumers in shifting from off-grid energy services which in turn gives energy consumers greater freedom to choose how and when to produce prosumption services (Parag, 2015).

2.2.2. Significance of Electric Vehicles in Smart Grid

The electrification of mobility in cities has become a national priority for European countries. This is due to climate change and increased need for energy policy makers across the world aiming to accelerate the adoption of environmentally friendly operations in energy and mobility sectors which together contributes to about 49 percent of Greenhouse gases released to the atmosphere (Bohnsack, 2014). Electric Vehicles (EVs) first appeared during the 19th century by a famous Engineer La Jamais Contente and was able to attain velocity of 100km/h (Beaume and Midler, 2009), but the publication on EV demand was made public in 1981 (Hinz, et al., 2015). Over the years, EVs have received considerate attention due to the progressive consumption of fossil fuels and the continuous awareness on environmental protection. EV refers to a motor vehicle partially or fully powered by an electrical motor that uses power from rechargeable storage batteries, PV arrays, fuel cells, or other sources of electricity (Wi et al., 2013). An example of EV deployment in smart grid is illustrated in Figure

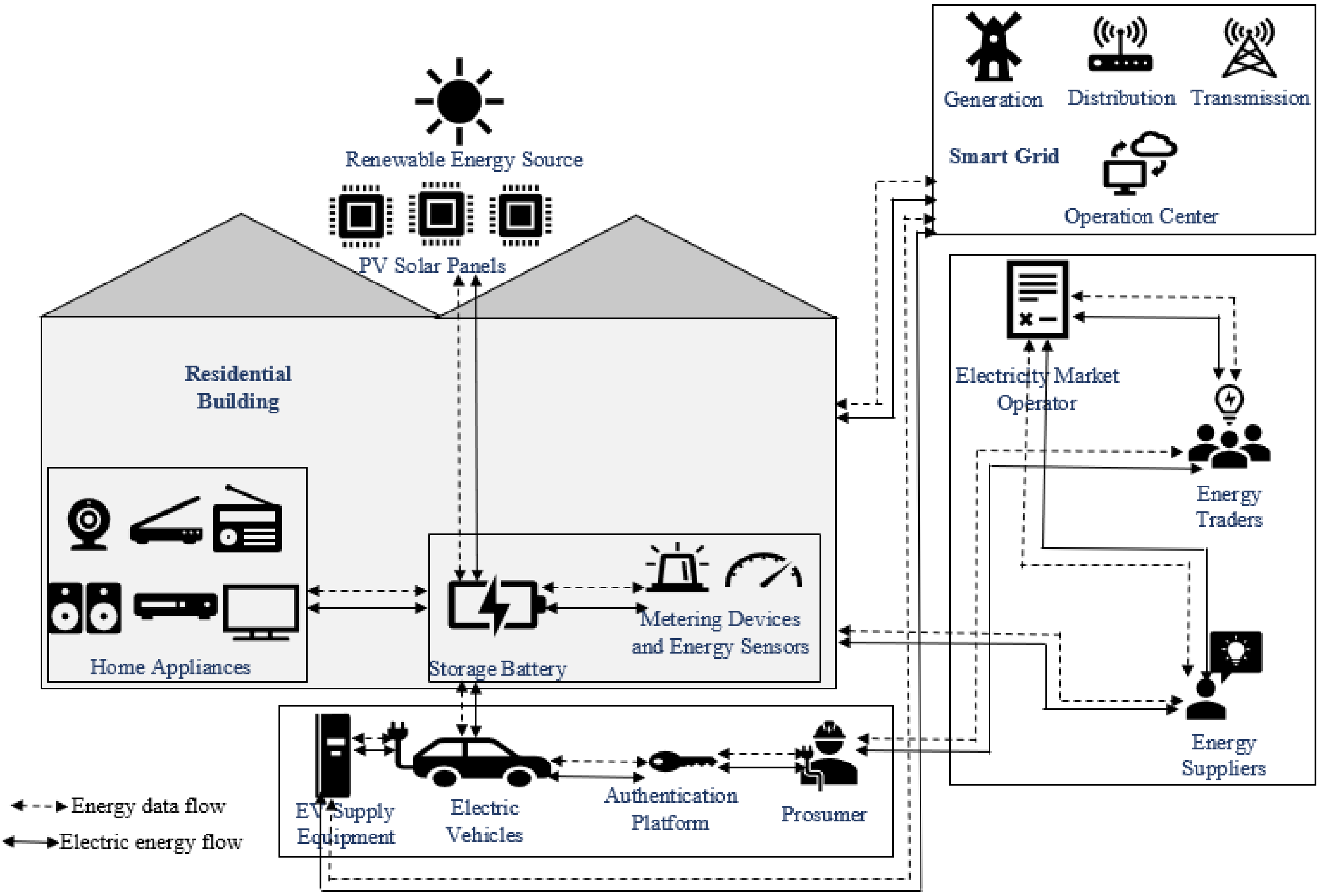

Figure 3 EV deployment in smart grid

Figure 3 depict EV deployment in smart grid which comprises of a trusted body such as an electricity market operator that plans the energy trading by managing energy traders and energy supplier. Next, is the EV which is a battery powered automobile that is connected to an EV supply equipment which is a device utilized for charging the EV. Moreover, the EV supply equipment is connected to the smart grid for V2G and Grid-to-Vehicle (V2G) operations. Followed by the prosumer who is the citizen that authenticates and uses the EV. The prosumer also makes payment subscription for his/her EV charging (Mustafa et al., 2014). An authentication platform is provided which is a tamper-proof hardware that stores prosumers payment and EV important data. The authentication platform employs cryptographic keys to ensures that valid user is given access to prosumption information. In addition, other actors include energy suppliers which is energy utility companies that is responsible for supplying electricity to citizens in the neighborhood and energy trader who is a broker that trades energy from the prosumer to other consumers in the grid. Within the house there are metering devices and energy sensors which are intelligent measuring device that records electricity usage of EV and home appliances in the building. Besides, Figure 3 entails renewable energy source which is an electricity source such as Photo Voltaic (PV) solar panel or wind turbine installed in the house to generate energy (Mustafa et al., 2014).

Likewise, with PV solar panels becoming inexpensive for households, energy consumers are growing into energy prosumers and EVs have been recommended as one solution that can lead to energy sustainability with renewable energy sources and V2G integration (Bellekom et al., 2016). This is possible since power transfer between smart grid and vehicles that utilize batteries, which could be deployed to disperse energy flow from EVs to the power lines and back as needed (Wentland, 2016). Although the deployment of V2G and G2V ensures that EVs must be installed with a link to the smart grid for data control with the grid operator, electricity flow, and vehicle on-board metering and control systems (Kotilainen, et al., 2017). Hence, EVs have digital controls to diversify sources of energy, decrease emissions, improve energy efficiency, and create economic value. Although researchers such as Bohnsack (2014) maintained that intrinsically EVs are not sustainable but the potential to improve power efficiency and decrease environmental effects relies on electricity source utilized to power the vehicle, stating that EV possess the capability to contribute towards sustainability, and lower CO_2 emissions. Thus, EVs are recognized as a key component in realization of smart city since their batteries can possibly be utilized as a remote and flexible energy storage (Kamargianni and Matyas, 2017).

2.2.3. Residential Energy District in Smart Grid

The smart grid can be referred to a power grid that intelligently integrate the actions and behavior of all end-users connected to provide secure, economic, and sustainable energy supplies (Dijk, et al., 2013). The smart grid also introduced prosumer in the energy chain (see Section 2.2.1) and provides intelligence to the entire energy grid by enabling flexibility in monitoring real time energy pricing in energy market providing bi-directional power and communication flows between energy consumers and suppliers (Parag and Sovacool, 2016). An energy district or neighborhood comprises of several prosumers that assume different level of operations that can vary from producing electricity for personal use to sharing surplus energy through the smart grid and becoming active contributors in energy industry. The smart grid enables citizens in community district to optimize their energy use according to their needs, when applicable, with preferences to energy production and storage (Wi et al., 2013).

This research considers a neighborhood or district that comprises of several households equipped with rooftop solar panels and a storage system as seen in Figure 4. Electricity generated by PV solar panels cannot always be utilized in real time by the household and is saved in a storage system, like a battery to be later consumed (Kotilainen, et al., 2017). In an energy district, prosumers are connected to a micro community grid managed through a centralized district energy management system as seen in Figure 4. The micro community grid is responsible for capturing energy flow information and disseminating the information to the district energy management system for analysis and processing towards supporting decisions making of prosumers regarding energy trading in their district (Parag and Sovacool, 2016). Thus, the prosumers can utilize the retrieved energy information to either offload their electricity demand or trade off their unused electricity to other energy consumers.

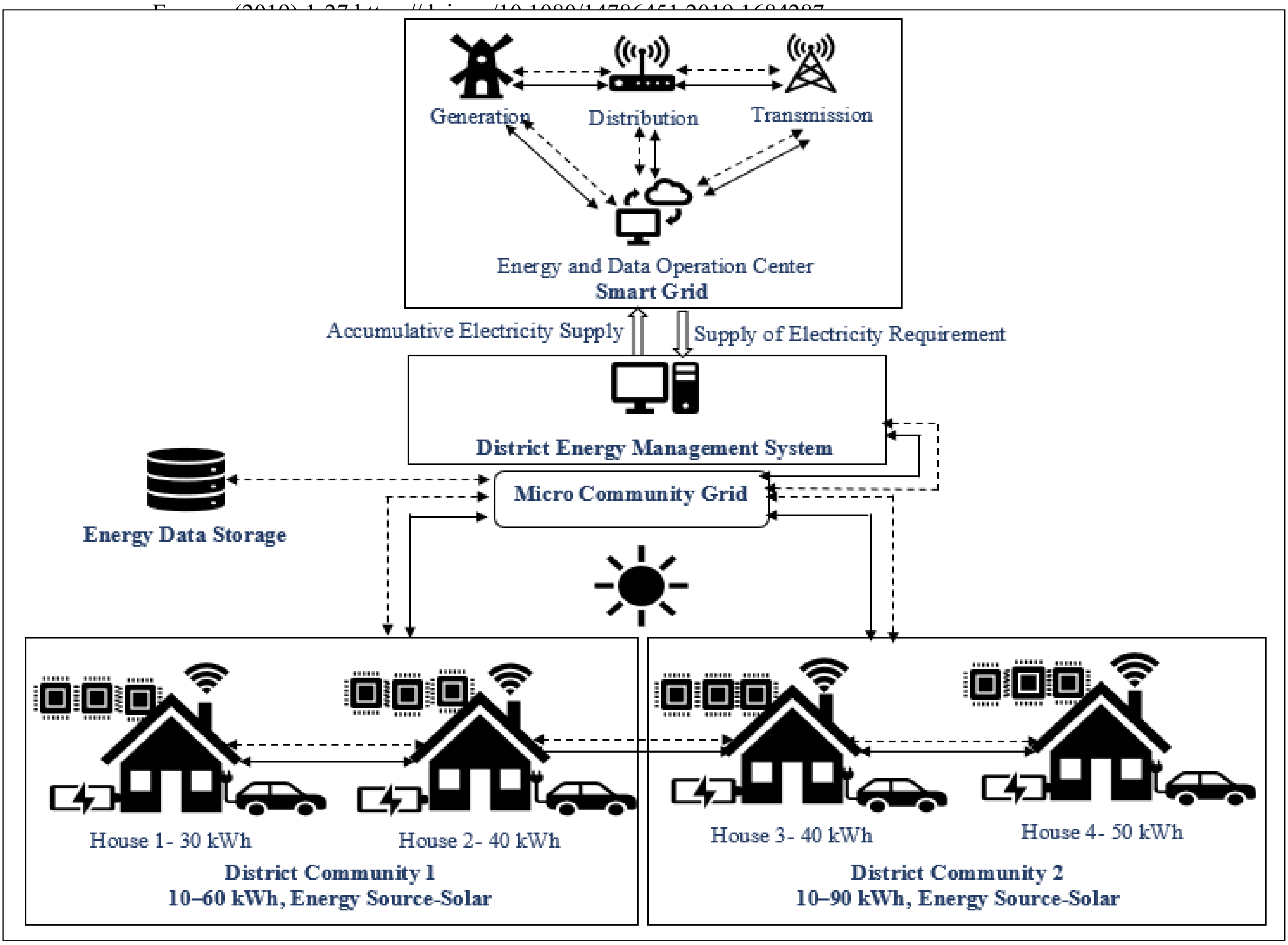

Figure 4 District community energy block and the smart grid

In the context of this study as seen in Figure 4, prosumers in the energy district are energy users who generate renewable energy via roof-top solar PV systems in their domestic environment and shares the extra energy to other consumers forming a community energy block. The surplus energy can be sold to energy retailers based on a pre-agreed contract between the prosumers and retailer (Wentland, 2016). Thus, this study is only focused on solar PV systems, since the infiltration of PV panels, is one of emerging sources in the renewable energy market. Besides, as seen in Figure 4 the deployment of PV systems aids prosumers to be sellers or buyer of energy depending on the circumstance and their total energy profile. However, during different time periods, a prosumer may switch his/her role to a seller or a buyer depending on the circumstance and net power profile (Espe et al., 2018).

Additionally, Figure 4 depicts the data and energy communication between the district community energy block and the smart grid which comprises of rooftop PV panels, peer-to-peer or prosumer-to-prosumer exchange of energy, in-home storage, EV, micro community grid, energy data storage, district energy management system, and smart grid (Parag and Sovacool, 2016). Hence, in a community district as presented in Figure 4 each resident building has its own characteristics such as annual energy requirement supplies as well as capacity of their storage battery and capability of installed PV system (Bellekom et al., 2016). Respectively, the concept of district community energy block in the smart grid aims to realize higher energy productivity and foster energy usage optimization. This can be attained by analyzing and monitoring not only energy components in the electricity distribution network, but also energy prosumers interactions within the district by collecting energy data that provides inferences on how manage real time energy demand and how energy can be saved (Patti et al., 2014; Brundu et al., 2016). The energy data can be exchanged and used to improve energy efficiency. However, the concept of community prosumers in energy district is still in its infancy (Parag and Sovacool, 2016), and little research has been employed to explore on how direct energy sharing or trading decisions between community prosumers and smart grid are executed based on energy data generated from energy devices (Silva et al., 2017).

2.2.4. Categories of Prosumption Models in District Communities

According to Parag and Sovacool (2016) there are three main energy prosumption models in smart cities and they include peer-to-peer, prosumer-to-grid, and organized prosumer groups.

a. Peer-to-Peer Approach

This approach involves a peer-to-peer system that allows energy consumers and producers to bid and directly trade and purchase electricity and other energy services. Within this approach, the energy distributor is remunerated with an administrative fee included with tariff for energy distribution depending on the source of energy, amount of energy service, and the distance between the consumer and provider (Parag and Sovacool, 2016). The peer-to-peer energy markets also involve several ad hoc or long-term relations between prosumer agents or partners where one consumer produces energy that is stored by another citizen, or between individual energy providers and consumers where, one citizen sells energy to another in the same district (Li, et al., 2017). This approach is efficient but is pose with issues related to how to provide available, accountable, affordable, and safe energy services to all prosumers in the same district. Hence, these progressively evolving energy markets would be required to adopt a certain set of guidelines and rules that are much complex than those pragmatically adopted in existing energy sharing economy approaches (Parag and Sovacool, 2016).

b. Prosumer-to-Grid Approach

The next approach comprises of a much-structured group of models that implements a brokerage energy system for prosumers that are connected within the micro community grid which is connected to the smart grid (Dijk, et al., 2013). Practically, each linked mode provides different energy incentives to prosumers since the microgrid is inter-connected to the smart grid, where incentives are provided for prosumers to produce as much power as possible, since extra power generated could be traded to the smart grid. Likewise, the trading of prosuming energy services through the local markets could improve energy management considerations and preferences of residential buildings (Parag and Sovacool, 2016). Thus, unified methods for integrating prosumers into the electricity system comprise of prosumption brokerage systems, prosumer marketplaces, and pre-defined sharing rules. Also, prosumers can offer to adjust their energy production or consumption in return for incentives or economic benefits based on energy market principles (Parag and Sovacool, 2016; Li et al., 2017).

c. Organized Prosumer Groups Approach

In this approach local prosumer markets operates in a smart city environment that offers opportunities for local districts, communities or neighborhoods to dynamically and efficiently manage their energy needs by considering local energy balancing services, prosumption resources, and stakeholder needs (Dijk, et al., 2013). This method also supports citizens to become prosumers by empowering district-based assistance and awareness programs to inspire local management of demand and supply of energy. Accordingly, districts or local communities could combine their prosumption resources to produce an income stream for the entire community benefit. Also, small and medium-scale energy firms may arise to act as providers or aggregators for distribution of energy services (Wi et al., 2013). Besides, this approach could be deployed like a traditional method analogous to energy companies that invest financially to deploy energy productivity upgrades and later have a share of the monetized energy investments, but they are not necessarily restricted to commercial energy sector (Parag and Sovacool, 2016).

2.3. Big Data Management for Energy Prosumption

Currently, data is considered as one of the most valuable assets in smart cities (Docherty et al., 2015), thus with the rapid increase in the presence of energy sensors, metering devices, EVs, appliances, and technologies, etc. in smart cities large amount of data known as Big data is generated which needs to be collected and processed for creating value-added services to citizens (Badii et al., 2017). Thus, these physical devices generate massive amount of data which relates to energy production and consumption per time interval, alarms, voltage, events, etc. (Khan and Kiani, 2012). Accordingly, energy data can be collection, harmonized, processed, analyzed, stored, and visualized in energy related application to provide knowledge for prosumers in making decision (Tcholtchev et al., 2012). Correspondingly, since data collected from districts comprises of various variety, veracity, velocity, and huge volume (Docherty et al., 2015), which cannot be processed by traditional tools.

There is need to deploy big data tools to process hundreds to thousands of gigabytes of data generated from physical devices in energy districts (Li et al., 2017). Therefore, it is vital for energy solutions to be able to manage volume, velocity, veracity, and variety of energy data (Khan and Kiani, 2012). Likewise, there is need for an architecture capable of employing layered paradigm to process huge amount of big data generated by energy devices at different velocity for exploiting and analyzing data towards making energy market predictions, detecting usage anomalies for early warning, and for producing recommendations and guide to prosumers and energy companies (Badii et al., 2017). In addition, the architecture should be designed based on a layered approach to support the robustness, capability, and scalability of processing, analyzing, and managing both real time and historical energy data as recommended by Tcholtchev et al. (2012). Moreover, the layered architecture can be employed as a reference for managing heterogenous data that are generated from energy districts (Rathnayaka et al., 2012). Then, API paradigm can be integrated to provide access to processed and saved energy data to prosumers and energy distributors to support energy production, use, trading decisions by providing knowledge towards the resilience, sustainability, and governance of energy districts in smart cities.

2.4. API for Big Data Management

An API referred to as Application Program Interface was proposed and patented in 1996 by Frank Bergler who defined API as an interface for integrated digital networks services such that application programs can be produced independently without the interference of network protocols (Choi et al., 2013). Thus, API enables communication of services and transfer of data between connected systems using pre-defined protocols via the internet which comprises of several devices with different languages that interoperate together (McGrath et al., 2019). Technically, APIs are standardized interfaces that supports exchange of data and facilitate human-to-machine and machine-to-machine communication (Raetzsch et al., 2019). Moreover, APIs uses a set of routines to facilitate digital application to communicate with a related system by describing the type of data that can be retrieved, procedure involved and data format in which the data should be presented. APIs provide links and access to specific databases, datasets, and web getaways (McGrath et al., 2019).

API can offer programmatic access to enterprise competencies and supports data sharing within and across energy districts based on two methods. First, APIs sets up a metering system that provides data access to a specific server or database and providing access to prosumers data via gateway. Secondly, contingent on whether the APIs are open or closed, APIs embodies the building blocks of integrated business process (Karnouskos et al., 2012). Thus, closed or internal APIs are only accessible within the enterprise intranet and are utilized to improve integration and prompt data sharing among employees in different departments. On the contrary, open or external APIs, aimed at promoting integration and collaboration with third parties such as prosumers, external energy companies or energy market operators by permitting them to gain access to explicit datasets. As such open API interfaces promotes modularity and interoperability which characterize the modern business process (Borgogno and Colangelo, 2019), which is one of the goals of the European Union (EU) which aims to support interoperability of datasets for a thriving smart city data-driven economy centered on the digitalization of innovations, services, and economies as drivers for sustainable development.

Accordingly, EU have started to advocate for the adoption of standardized, open, APIs with interoperable, coherent protocols and formats for collecting and processing of data from different sources in smart cities (McGrath et al., 2019). Hence, APIs are traditionally employed as glue for improving data integration to increase flexibility of data access into application simplifying the dissemination of data and exposing new business functionality such as prosumption operations to citizens across smart city (Holley et al., 2014). Currently, APIs are utilized by leading IT firms such as Google, Dell, and Yahoo to promote open data for improving their service (Choi et al., 2013). APIs are core to providing access to open data. Although, APIs like any other application products have policies that govern their use ensuring their maintenance and life cycle (Holley et al., 2014). Thus, APIs can be deployed for sharing energy data regarding prosumption operations to create opportunity to manage cost flexibility for electricity trading in the energy market place towards predicting current and future trading (Holley et al., 2014). In energy trading, API economy (open external API platform) is vital to develop an energy data ecosystem that ensures that energy data is not trapped in silos (Raetzsch et al., 2019). Such APIs can be invoked by prosumers, energy service provider, other stakeholders via any Internet-enabled endpoint browser or mobile device to access district energy data that can be utilized to create new business opportunities.

2.5. Related Works

Over the years, many researchers have developed architectures that integrates API for smart city services such as to improve energy consumption optimization and mobility. Accordingly, the most relevant studies related to this research are reviewed in Table 1. Based on the reviewed studies (see Table 1) there is lack of a study that examines the processing of heterogenous real time and historical data to be analyzed to support energy prosumption services in energy districts. However, researchers such as Vögler et al. (2016) deployed cloud approach to process real time and historical data, Simmhan et al. (2018) enable data processing for smart services, and Mokhtari et al. (2019) explored real time and static data management in smart homes. None of the studies employed both real time and historical data to facilitate energy prosumption services.

Similarly, none of the studies employed both MQTT protocol and Hypertext Transfer Protocol (HTTP) via RESTful API to support energy prosumption services, although MQTT and HTTP protocols was adopted by Soto et al. (2015) to improve interoperability among devices, Brundu et al. (2016) to enhance energy services in residential building, and Patti and Acquaviva (2016) to manage huge amount of energy data. The researchers did not explore MQTT and HTTP protocols for energy prosumption services related to EVs and smart grid. Thus, this study employs both real time data using MQTT protocol and historical and online data from application using HTTP Restful APIs in the proposed layered architecture to enable interoperability across heterogeneous devices to manage renewable energy prosumption in achieving a positive energy district and increasing energy trading in smart cities.

Table 1 Prior studies on API integration for big data towards smart services

Authors & Contribution	**Purpose**	**Layers/Components**	**Big Database Technology**	**Communication Technology**	**Protocol(s)**	**Service(s)**
Mokhtari et al. (2019) designed a layered architecture for data-driven management in smart homes.	Intended to provide data-driven services to third-parties and several smart home applications.	Physical, service, cloud-computing, fog-computing, application network, and session layer.	Batch and real-time processing.	Iwave, Wi-Fi, and Bluetooth.	Infused REST API for HTTP response request services.	Used RESTful API to achieve smart home energy management.
Simmhan et al. (2018) developed a data-driven architecture for smart city services.	Aimed to address the management of smart applications for service towards decision-making.	Sensing, actuation, networking and communication, data acquisition and curation, data analytics and visualization, and decision making.	Storm, HBase and HDFS, Spark and SParkQL.	2G, 3G, 4G, Bluetooth connectivity, wired or wireless LANs, IEEE 802.15.4, ZigBee, and Lora WAN.	Ad hoc and peer-to-peer (P2P) web protocols.	JSON, MQTT, and REST was employed for data services.
Brundu et al. (2016) proposed an infrastructure that supports energy simulation and management policies in city district.	Aimed to facilitate interoperability of near-real-time energy data from sensors.	Devices and technologies integration, services, and application layer.	Relational database deploying SQL queries and retrieving JSON results.	Supervisory Control and Data Acquisition (SCADA) and Wireless sensor network (WSN).	REST based on request/response for nonreal-time and MQTT based on publish/subscribe for real-time services.	Utilizes JSON-based RESTful API to get energy services.
Chang and Lo (2016) proposed a plan on how to achieve smart city.	Aimed to improve citizen life and uncover new opportunities.	Physical machine, data platform, middleware platform, App engine and APIs.	Cloud management platform	4G LTE, Wi-Fi, and Near-field communication (NFC)	Web portal and APIs.	Uses APIs to facilitate energy management to save electricity.
Giatsoglou et al. (2016) implemented a platform prototype for enhancing smart city social data mining.	Aimed at providing modular system grounded on social data analysis in smart city context.	Data analyzer, data collector, and data aggregator.	Social media APIs and JSON format.	Social data mining based on numerous parallel data stream.	Twitter streaming API, Flickr API, and Foursquare venues platform API.	Uses social media API data for discovering information in terms of emerging trends.
Schleicher et al. (2017) modelled available data sources to aid efficient data access in smart cities.	Aimed to address compliance and security related to data sources.	Provider, smart city operating system, demand (consumers), application, and infrastructure.	Employed MongoDB, SQL schema, JSON schema.	Utilized OAuth.	RESTful microservices implemented in Ruby, RabbitMQ for messaging.	Integrated RESTful to manage constrains in smart city data.
Gutiérrez et al. (2016) researched on empowering residents toward the co-creation of smart cities.	Focused to create opportunity for exploiting data within connected city innovation.	Application, APIs, repository, data sources adaptation interoperability, communication networks, devices, legacy systems, and other platforms.	Used a transversal intelligence data repository.	FIWARE NGSI specification facilitate the interoperability of smart city solutions.	Employed an Experimentation as a Service (EaaS) API to facilitate access to smart services.	Deployed OAuth2.0 to provides either user interface for end-users or a programmatic API usually RESTful.
Pflügler et al. (2016) developed an open platform architecture to improve mobility services in smart city.	Aimed to provide data to improve mobility services.	Solutions, integration layer, layers of modular services, and data sources.	Open mobility services database	Google and Bing maps.	Employed APIs.	Big data to improve mobility service.

Table 1 *Continued*

Authors & Contribution	**Purpose**	**Layers/Components**	**Big Database Technology**	**Communication Technology**	**Protocol(s)**	**Service(s)**
Silva et al. (2017) investigated how big data can be integrated in RESTful web of things architecture for efficient energy management service.	Intended to present a smart building architecture to improve the performance of energy management in smart buildings.	Smart gateway enabled WoT, application, event and decision management, data creation and collection, communication medium, and data processing and management.	MapReduce, HDFS, and HBase.	3G, 4GLTE, Wi-Fi, Zigbee and Bluetooth.	RESTful API for service translation and transport module between web server and smart gateway.	Employed RESTful API to exposing smart city services for energy management.
Vögler et al. (2017) implemented a cloud-oriented distributed big data management framework.	Meant to aid in performing offline and online analyses of collected data to optimize smart city services.	User API, repositories, messaging infrastructure, and the stream processing layer.	Apache Spark and Apache Spark Streaming deployed in Hadoop cluster and repositories.	Employed Lambda architectures.	Used publish subscribe mechanism user API.	Autonomously analyze both historical and online data from smart city applications.
Patti and Acquaviva (2016) proposed a distributed system managing huge amount of energy data.	Focused to improve interoperability among heterogeneous devices for energy management.	Data-source integration, district services, and application layer.	NoSQL database (MongoDB or InfluxDB).	Zigbee, EnOcean technology, and SCADA.	Employed REST API and MQTT protocol for publish/subscribe of data services.	Deploys both request-response and publish-subscribe protocols to improve energy efficiency and create services.
Robinson et al. (2016) deployed API to achieve an integrated open data platform for cities.	Focused to present the concept and vision of street oriented computing.	Data sources, substrate, composition, interface, and application layer.	Collects data from heterogeneous sources and sensors data streams.	Uses mashups from web-based data.	Utilized publish and subscribe approach of communication.	Used open data API to improve urban development.
Vögler et al. (2016) proposed a cloud-oriented smart city application eco-system.	Aimed to promote incorporation of stakeholders and resources to proficiently, design and deploy smart city applications.	Application, data, and infrastructure layer.	Includes Amazon IoT, Google Cloud Dataflow, Amazon Elastic MapReduce, Apache Quarks, and Esc.	Google's Monitoring API.	Employs pull and push based updates.	Deployed APIs to support implementation of custom drivers and resources required for new forms of interactions.
Soto et al. (2015) designed a platform that supports interoperability among devices in smart city applications.	Aimed to provide a platform as a solution which handles heterogeneity of data.	Data management, intern communication BUS, devices and legacy platforms, cloud APIs an application, and federated network.	Data-Fusion Manager	TCP/IP protocol	Employed HTTP and MQTT protocol.	Employs cloud-based APIs to address interoperability issues.
Khan et al. (2014) proposed a framework for cloud-oriented context-based data services for residents in smart cities.	Aimed to demonstrate the efficiency of cloud-oriented infrastructure for deployment of smart services for citizens.	Platform integration, data acquisition and analysis, thematic, service composition, application service, management and integration, and security layer.	Cloud-based infrastructure	Cloud computing data storage and processing.	Employed APIs	Provided context aware citizen centric services in smart cities.

Table 1 *Continued*

Authors & Contribution	**Purpose**	**Layers/Components**	**Big Database Technology**	**Communication Technology**	**Protocol(s)**	**Service(s)**
Lea and Blackstock (2014) proposed a hub-based approach to provide data to support smart city projects.	Aimed to facilitate access to data and create a medium for citizens to crowd-sourced smart city data.	City sub systems, real time and static data sources, and Hub REST API.	Data was collected from URLs, querying catalogues and data hubs.	Utilized OAuth2.	RESTful web services.	Uses APIs that allows developers to query, search and download relevant smart city datasets.
Patti et al. (2014) developed a software platform for managing district energy.	Intended to provide a digital library of the city in which energy information is made open.	Devices, integration, middleware, and application layer.	Meta-data about sensors, actuators, and District Information Modelling (DIM) database.	802.15.4, ZigBee, OPC proxy, and EnOcean proxy.	Simple Object Access Protocol (SOAP) for requested service endpoint using publish/subscribe approach.	Integrated API to implement application to enhance citizens awareness.
Sánchez et al. (2013) designed an architecture to address the issues that mitigate against smarter city development.	Aimed to create added-value services that can be seamlessly created to achieve sustainable cities.	Heterogeneous data source, capillary networks, utility and legacy systems, network backbone, enabling devices, and services and applications.	MySQL	IEEE 802.15.4 and 3G connection	Implemented a RESTful API that provides access to PUT and GET services.	Deployed RESTful API based on XML, JSON using HTTP POST/PUT.
Vilajosana et al. (2013) developed a self-sustainable big data flows model for smart cities.	Aimed to suggest a method to facilitate big data exploitation through the application of API.	Capillary networks, API, filtering and post-processing, services, web service open data APIs, and application.	Under sampling, Pattern recognition, Kalman filtering, and Interpolation.	Capillary network management and scalable data storage.	Utilized open data APIs and web services.	Exploit open data APIs to improve smart city services.
Karnouskos et al. (2012) investigated how energy services can be improved in smart grid city.	Focused on providing services to support end-users to monitor energy, trade energy, and assess energy efficiency of appliances.	Mashup applications, operator, public services, smart grid devices, and enterprise integration and energy management system.	MySQL database	Java REST services and web sockets are deployed in Glassfish and cloud.	Integrated HTTPS RESTful web service with PUT, GET, DELETE, POST methods.	Used RESTful API to enhance neighborhood energy management.

3. Design Methodology

This Section presents background of RESTful API deployment, overview of MQTT, comparison of HTTP and MQTT for energy services, and the developed layered architecture.

3.1. Background of RESTful API Deployment

The most widely architectural protocol for web-based applications is Representational State Transfer (REST) which was proposed by Roy Fielding (Fielding and Taylor, 2000) for deploying large scale distributed systems based on client server, which suggest that deployment on each side can be accomplished separately. REST protocol employs a stateless procedure which suggest that each call comprises of information essential for execution and thus does not require status information from prior calls to be implemented (Karnouskos et al., 2012). Over the years, REST APIs has become a vital component which allowed the dynamic pull of data from different databases in response to end-user's requests or inputs, instead of pushing same static information to every user. REST is also suitable based on its tolerance and flexibility for third-party designers to develop web-based applications (Raetzsch et al., 2019). APIs utilizes sets of methods that supports client-based applications to interact and transmit data such as energy data using JavaScript, REST, Simple Object Access Protocol (SOAP), and other web approaches for transmitting structured information (Chaturvedi and Kolbe, 2018; McGrath et al., 2019). REST services are among the most widely deployed web services in use today, due partly to its simplicity and robust architecture that uses less bandwidth for connecting services. Although, few enterprises utilized other web service protocol such as Simple Object Access Protocol (SOAP) (McGrath et al., 2016).

However, SOAP has a complicated web-based service characteristic, unlike REST web service which is less complex, it excludes overhead from encoding and decoding of header and body throughout message transfer to support developers and users to easily deploy web services at local or remote sites (Raetzsch et al., 2019). Hence, REST helps to simplify deployed API implementation, as well as to support rapid application integration via the Internet as recommended by Karnouskos et al. (2012). Likewise, REST web service is popularly being deployed for development of web and mobile application and is being utilized by leading enterprises such as Twitter, LinkedIn, Amazon, etc. to deliver API services linked to data sources (McGrath et al., 2019). Figure 5 depicts an energy data transfer that employs a standard REST protocol which comprises of a prosumer who is the client using a third-party application to produce a Uniform Resource Locator (URL) that is sent to the micro community grid server using a basic HTTP GET request. The Get request is called to receive request at the micro community grid server and is processed by the energy API (Chaturvedi and Kolbe, 2018). Thus, the HTTP RESPONSE is the computed energy produced or consumed data, formatted as JavaScript Object Notation (JSON) or eXtensible Markup Language (XML) as seen in Figure 5.

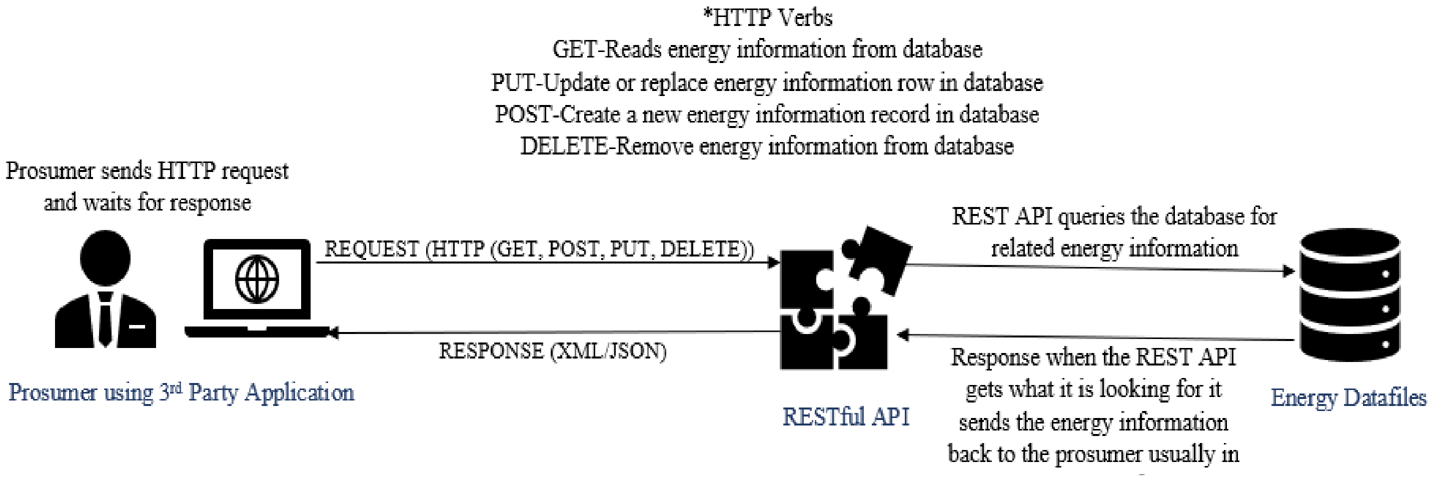

Figure 5 Applicability of REST API for transferring energy data

3.2. Overview of Message Queuing Telemetry Transport (MQTT)

MQTT is an extremely lightweight and simple messaging protocol that uses publish/subscribe (pub/sub) and is designed for low-bandwidth constrained devices that employs unreliable networks or high-latency. MQTT was developed in 1999 by Andy Stanford-Clark (IBM) and Arlen Nipper. MQTT aims to reduce network bandwidth and resources required by devices while ensuring reliability and delivery assurance (Vernet et al., 2015). The principles adopted by MQTT makes it suitable for evolving machine-to-machine (M2M) connections where battery power and bandwidth are at a finest. MQTT is more suitable for connecting energy metering devices and sensors in energy district due to its small headers and minimum overhead. Moreover, MQTT can also be deployed over Secure Socket Layer (SSL) to implement security (Patti and Acquaviva, 2016).

It's designed on a messaging technique, easy to integrate in smart city energy and mobility hardware devices and fast in transmitting data. It executes in real time, thus its appropriate to collect data produced by energy metering devices and sensor in energy prosumption services using low power usage which results to saving the battery of connected devices thus appropriate for connecting physical measuring devices in smart city applications (Vernet et al., 2015). In the context of this study MQTT server is referred to as a broker and the connected devices or clients are the end users such as the prosumers and energy service providers as shown in Figure 6.

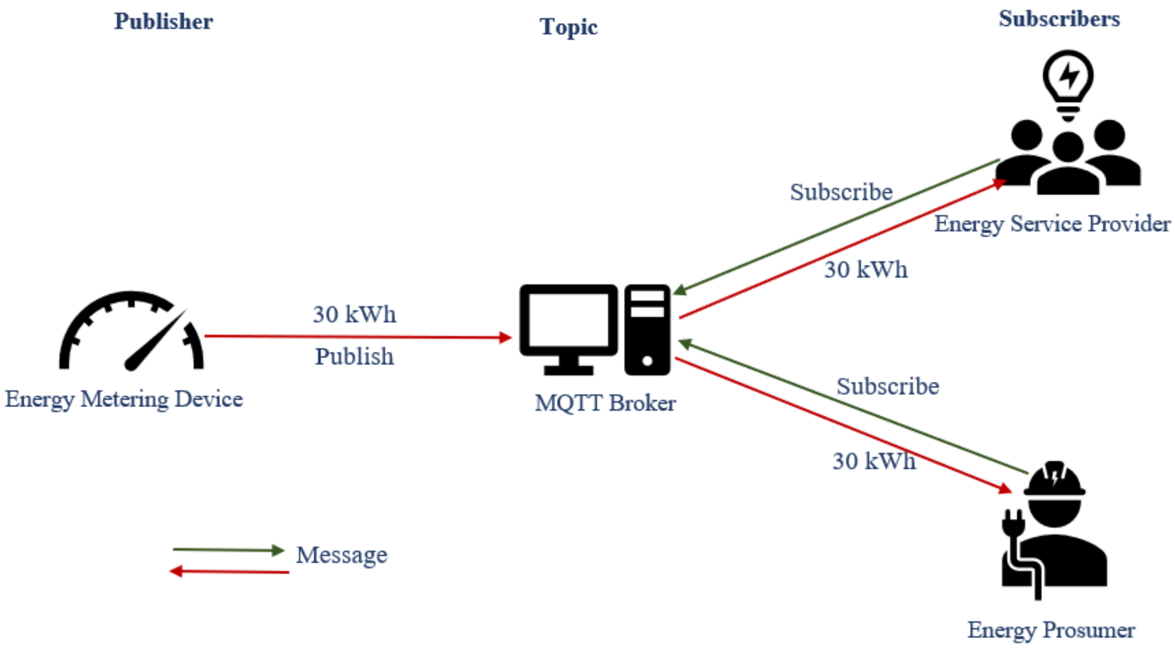

Figure 6 MQTT energy data flow from energy metering device to server and clients

Figure 6 depicts the MQTT schematic energy data flow from energy metering device to server (MQTT broker) and clients (energy service provider and energy prosumer). The energy service provider and energy prosumer publish by sending data to the broker, whereas the energy service provider and energy prosumer subscribe when they want to receive data from the broker. In addition, service provider and energy prosumer are publishing and subscribing to energy consumption and production topics handled by the MQTT broker who manages the publishing/subscribing schedules related to energy topics. Similarly, the topic refers to a place a device intends to retrieve or put a message to and from (Simmhan et al., 2018). Next is the message which is the energy data that the energy metering device receives when subscribing from the energy topic or sent when publishing on energy topics. As seen in Figure 6 the message is 30 kWh of energy which is publish as a process a device employs to send generated energy message to the broker and subscribe, where energy service provider and energy prosumer retrieve energy message 30 kWh from the broker.

3.3. Comparison of HTTP and MQTT for Energy Services

HTTP and MQTT are compared based on certain features to evaluate which protocol is more suitable to be integrated in the proposed layered architecture. This helps to specify which protocols can be adopted to support the collection and transfers of energy data to prosumers and energy service providers in achieving a positive energy district and increased renewable energy trading. Thus, Table 2 shows the comparison of both protocols.

Table 2 Comparison of MQTT and HTTP protocol

Features	MQTT	HTTP
Push transfer of data	MQTT deploys low latency push from server to client and from client to server.	HTTP pull from server to client and Push from client to server.
Resourceful use of network	MQTT utilizes almost 5 times less bytes as compared to HTTP.	HTTP requires 5 times more bytes.
Quality of Service (QoS)	Maintain and even QoS across network connection breaks.	QoS in HTTP is not even across connection.
Reliable delivery	MQTT deploys low latency push from both server and client.	HTTP requires more latency to operate.
Design	Mostly data oriented.	Mostly document oriented.
Message procedure	Publish and subscribe.	Request and response.
Complexity	Quite simple.	Mostly complex.
Message size	Small based on binary with 2B header.	Usually large and based on ASCII.
Service levels	Usually Three.	Mainly one.
Deployed libraries	30 kilobyte C and 100 kilobyte Java.	Use large kilobytes.
Data distribution	One to zero, one, or n.	One to one only.
Upper layer protocol	It is executed over Transmission Control Protocol (TCP).	It is mostly executed over TCP and User Datagram Protocol (UDP).
Data security	Yes, it provides security based on Secure Sockets Layer (SSL) and Transport Layer Security (TLS) protocols.	No security is not provided but usually employs Hypertext Transfer Protocol Secure (HTTPS) to provide data security
Encryption capability	It encrypts data payload by using payload agnostic method.	Data are usually not encrypted before transmission.
When to use	For device to device communication MQTT can be easily integrated.	Its more suitable to collect big data from various sources and applications.

In summary, HTTP is much slower due to added overhead but is much robust as compared to MQTT. This is because HTTP employs bigger data packets to connect with the server. Also, in relation to overhead HTTP opens and closes connection at each request, whereas MQTT is always active to ensure that there is an open channel between the clients and server (Soto et al., 2015). Moreover, for power usage since HTTP takes more time to transfer data packets it consumes more power. But HTTP is an extendable and provide quality data transfer service for smart city applications, however MQTT is more appropriate for device to device communication for smart city development. Therefore, in this study both HTTP via REST API and MQTT are integrated in the developed layered architecture to managing real-time, online, and historical data of energy data in the context of residential buildings and EVs in achieving a positive energy district.

3.4. Developed Layered Architecture

This study develops a layered architecture that comprises of seven layers (context, service, business, application, data space, technology, and data sources). Thus, the developed layered architecture enables positive energy district and increase energy trading as presented in Figure 7;

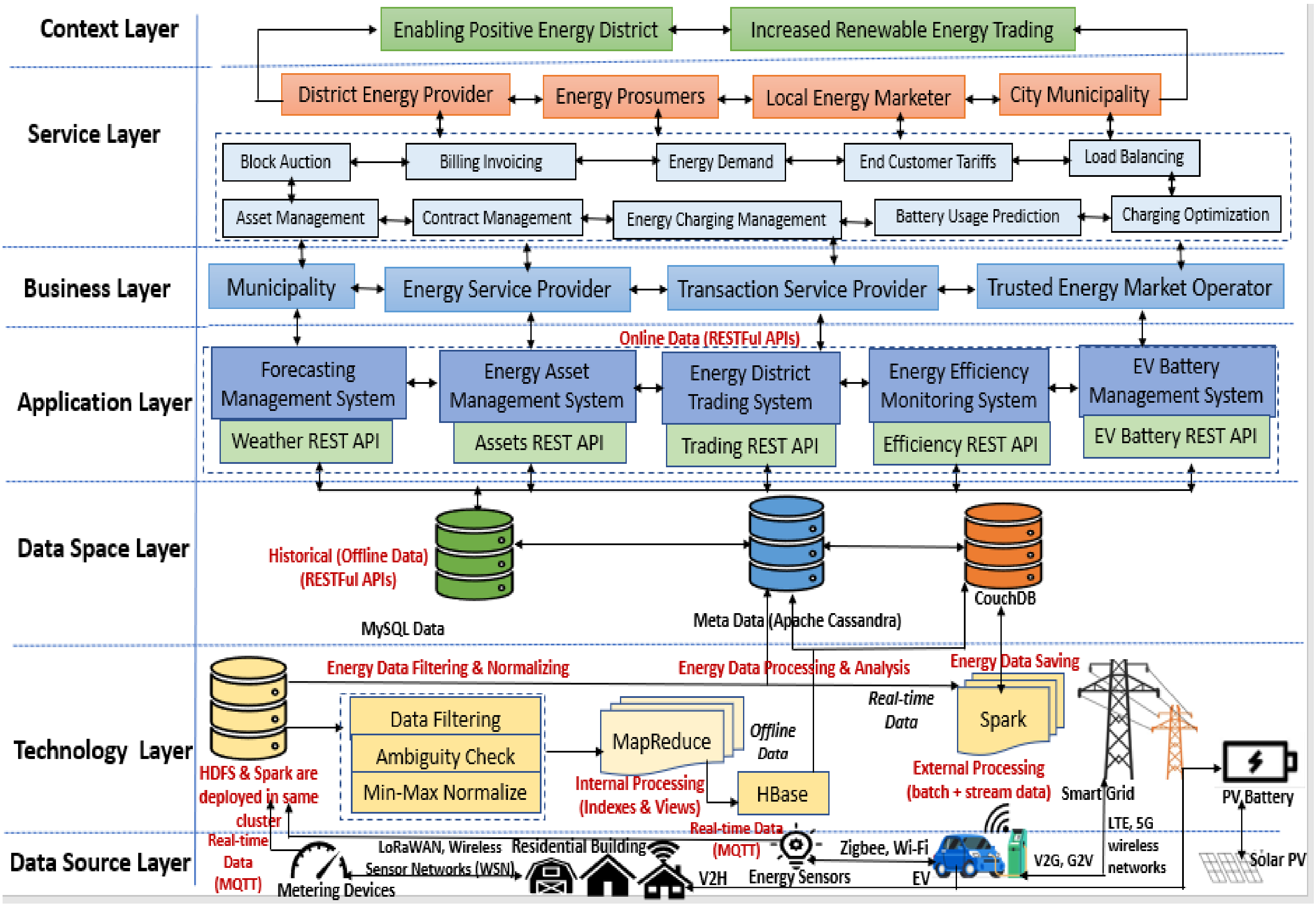

Figure 7 Developed layered architecture for energy district

Figure 7 depicts the developed layered architecture, each of the layers is discussed below;

3.4.1. Context Layer

This layer is an abstract representation of the main feature or target to be attained within the architecture (Abu-Matar and Davies, 2017). In the context of this study the context layer encompasses the motivations and requirements towards achieving an energy district in smart cities. Thus, it involves the Key Performance Indicators (KPI) to be achieved towards improving prosumption services facilitated by APIs for interoperability of energy data produced from energy devices. Therefore, the context layer presents the aggregated expectations of prosumer, energy service providers, and all stakeholders involved in energy prosumption operation. As seen in Figure 7 the developed layered architecture, context layer comprises of enabling positive energy district and increased renewable energy trading.

3.4.2. Service Layer

Service layer links prosumer, energy service provider and stakeholders to enhance quality of life of citizens (Silva et al., 2018). Besides, service layer also allows trusted third parties such as energy retailer, market operator, distributor, etc. to update existing services or add new services to be utilized by citizens. Also, single energy related services can be integrated to provide more composite services in producing a value-chain of services to citizens and stakeholders (Robert et al., 2017; Tcholtchev et al., 2017). Additionally, the services layer may also provide specific functionality to application layers via business layer over protocols such as HTTP to be accessed by APIs from several devices (Anthopoulos and Tsoukalas, 2006). The resulting service procedures and data are utilized for supporting decisions on the energy prosumption strategies for energy block auction, energy charging management, asset management, battery usage prediction, etc. that can be employed to enhance prosumption options in smart city (Bellini et al., 2018). Therefore, this layer comprises of various smart city services that are part of the energy prosumption and trading in smart city. The services are aligned to the business context that offers sophisticated functionalities (Junior et al., 2018).

3.4.3. Business Layer

The business layer denotes organizations related to energy operations in smart city (Winter and Fischer, 2006). This layer categorizes and specifies the different enterprises involved in energy prosumption and trading in smart city. The business layer thus contributes to the sustainable development of flexible energy trading market models that can be adopted by prosumers and energy service providers in energy district. Moreover, this layer comprises of many business processes performed across boundaries and realized by different applications driven by services (Abu-Matar and Davies, 2017). In energy districts, the strategic management of business layer is influenced by market and government forces (Winter and Fischer, 2006). In addition, the business layer stipulates the foremost activities and interactions of enterprises connected with each other and verifies whether all participating enterprises required to achieve positive energy trading and flexible energy market have been specified, or whether all stakeholder required for running the energy market process are available (Otto et al., 2017).

3.4.4. Application Layer

This layer offers a set of tools and APIs to develop systems to manage and post-process generated real-time streaming data from metering devices and energy sensors, online data from energy related applications and offline historical data (Brundu et al., 2016; Petersen et al., 2019). In this layer sets of tool and API are provided to develop remote application for addressing interoperability issues for managing energy consumption and production operation of residential buildings and EVs connection to the smart grid (Silva et al., 2017). Besides, application layer aids the deployment of request/response by HTTP RESTful APIs (Brundu et al., 2016). Hence, this layer provides applications that exposing smart city energy services to support the actualization of an energy district. Hence, RESTful APIs are integrated to facilitate applications such as forecasting system, energy asset management system, energy district trading system, energy efficiency monitoring system, EV battery management system, etc. that provides real-time data from pervasive energy sensors (Vögler et al., 2016).

Correspondingly, applications layer provides virtual energy district information that can be utilized to implement policies to enhance energy demand and optimize energy consumption of community district (Mokhtari et al., 2019). Such information can be used by single apartment or energy suppliers to monitor and maintain energy distribution network to improve awareness of district inhabitant's energy usage and production in promoting sustainable energy-friendly behaviors (Patti et al., 2014). Thus, this layer uses data from data space layer in specific programs and tools to execute contextual analysis for decision-making. Furthermore, this layer facilitates stakeholders to use existing APIs to develop new applications for specific services to provide contextual energy information needs of consumers (Khan et al., 2014). Also, this layer provides a uniform CRUD interface that enables prosumers, energy service providers, and other stakeholders to carryout HTTP create, read, update, and delete operations represented in XML, JSON, and HTML format (Paganelli et al., 2014).

3.4.5. Data Space Layer

This layer provides massive processed data storage for online, historical as well as streaming real-time data storage to support the application layer (Silva et al., 2018). According to Abu-Matar and Davies (2017) the data space layer is the heart of the architecture as it provides all the data management, data exploitation and dissemination capabilities required to support interoperability and openness of energy related data to systems that uses the data via the application layer (Cox et al., 2016). Besides, this layer offers the possibility to upload data in formats such as XML, CSV, and JSON, and further store linked data and provides access to the data over RESTful API interface to generate valuable insights, for example by using SPARQL query language over a SPARQL endpoint to provide stored information on energy consumption and production (Vögler et al., 2016). Although, most the data sources come with a set of regulating usage policies (Khan et al., 2014), where the data can be catalogued as public, classified, or private data. (Anthopoulos and Tsoukalas, 2006).

This layer comprises of relational and non-relational databases such as MySQL database, Couch database, and meta-data records that describe the data which is accessible over the RESTful APIs (Patti et al., 2014). This layer also includes data which is provided by external sources as well as imported data (Tcholtchev et al., 2017). These data sources include metering devices, energy sensor data, public energy data, energy trading data extracted from the web or provided by government, public establishments and other organizations, for instance the municipal energy provider (Chaturvedi and Kolbe, 2018). All these processed data are catalogued and stored as datasets by data space layer in order to provide energy prosumers with services that are based on these data accessed by APIs in various forms making the data space layer to be self-sustainable (Khan et al., 2014). Then the data is mapped using standardized resource description semantics, for example via a Resource Description Framework (RDF) store which has all the required links established between resources and artefacts, and then SPARQL, an RDF query language is employed to retrieve and manipulate data stored in database such as Cassandra and Couch database (Silva et al., 2018).

3.4.6. Technology Layer

This layer represents the physical components that underlie energy districts in smart cities (Abu-Matar and Davies, 2017). It includes networking, communications infrastructures, energy transaction management, orchestration devices and big data computing tools (Cox et al., 2016). This layer denotes the control mechanisms of hardware devices such as smart grid, PV battery, produced energy data processing tools, etc. (Grijalva and Tariq, 2011). This layer is responsible to efficiently process and analyze energy related data generated from the data source layer, by supporting the plethora of different data formats and the intrinsic variety of data, and further process noisy data produced by energy devices (Vögler et al., 2016). Furthermore, the technology layer provides mechanisms to proficiently transform and analyze these large sets of heterogenous data and facilitates the processing of streaming real-time, online, and historical energy data, which is an important aspect of smart cities.

Accordingly, heterogenous real-time data are collected from energy metering and sensor devices in the data source layer. The collected energy data are managed by filtering, normalizing, processing, analyzing, and storing of the energy data (see Figure 7) to be utilized by prosumer, energy service providers, and other stakeholder to improve energy trading in energy districts. Hence, this layer comprises of energy data filtering and normalizing, energy data processing and analysis, and energy data storing. For data filtering and normalizing aggregated energy data are transferred to the technology layer to which are stored temporary in Hadoop Distributed File System (HDFS) repository to determine and sort the valuable data from the gathered raw data via data filtration and data analysis. Respectively, HDFS is the native Hadoop data management system that offers a reliable, high performance scalable, fault-tolerant, and distributed data storage. It is developed to manage large clusters of service servers and maintain large volumes data files. It supports file creation, write once, read many and remove operations but does not permit update operations.

This study employs data filtration and min-max normalization techniques as recommended by Silva et al. (2018) to improve energy data. Also, data normalization is employed as a data pre-processing procedure to helps maintain the reliability of collected energy data which is heterogeneous and voluminous with an extensive portion of redundant, ambiguous, and erroneous data. Thus, data normalization decreases the needless excess load on the Hadoop processing cluster. Likewise, data filtration process eliminates corrupted or noisy data from the energy dataset, thus easing Hadoop cluster load. Energy data generated from metering devices and energy sensors, appliances, EVs, etc. are either semi-structured or unstructured. This is significant as heterogeneous energy data collected comprises of erroneous data, which may result to faulty outcome for prosumers and energy service providers in energy districts. Moreover, ambiguity check is incorporated into the energy data processing to screen semi-structured data as this helps to define parameter for each corresponding rule employed to pre-define ambiguity check in advance.

Respectively, for data processing and analysis the filtered and normalized energy data are moved to data processing phase which is the central task of the layered architecture. The data processing involves the processing of offline data mostly derived from historical energy data or online data from applications, and real time energy data. To proceed with energy data processing a group of big data management tools including HDFS, HBase, MapReduce, and Spark are deployed to facilitate energy data processing. HBase is a NoSQL data repository deployed on HDFS to stores semi-structured energy data collected from the energy devices. The motivation for utilizing HBase is to improve performance of data processing, real-time lookups, server programming, and in-memory caching. Besides, HBase aids in improving usability and is mostly fault tolerant in gathering semi-structured data in JSON file format. For energy data processing HBase is employed to execute both data filtration and normalization processing. Next, the min-max filtered and normalized energy data from mistakes, ambiguity, and redundancy data are analyzed using MapReduce technique. MapReduce offers a powerful programming framework for distributed and parallel processing of big data on clusters. MapReduce platform is mostly characterized by the aptness of its functionalities in maintaining load balance, deploying cost effective, flexible, and processed power, etc. (Osman, 2019).

Thus, MapReduce analysis aims to execute offline processing of large sets of historic energy data such as energy consumption or production logs data. The offline data processing is important as it helps to assess changes that occurs over time in relation energy trading in forecasting and prediction the energy market for prosumers and energy service providers. Therefore, MapReduce maps filtered energy data into diverse data sets and then linked mapped data are combined to produce smaller datasets. Besides, HDFS is utilized as a storage medium of energy data, owing to its distributed nature and scalability which aids in big data processing. Since SQL queries are not acceptable on Hadoop cluster, Apache Spark manages querying of large energy datasets on HDFS. As the unstructured heterogenous real time energy data from metering devices and energy sensors are voluminous as compared to offline historical energy semi-structured data, unstructured real time energy data are processed and analyzed extensively before storing in HBase. Moreover, to improve processing capability of HBase, the voluminous unstructured real time energy data processing from metering devices and energy sensors are not performed in HBase.

Instead, real-time unstructured energy data processing is managed by Spark, which analyzes real-time decisions from streaming energy data. Apache spark is a batch in-memory technique that performs micro-batch processing via Spark-streaming. It is an efficient substitute to Hadoop MapReduce technique as it provides faster performance and it offers smart applications processing for online and real-time applications (Osman, 2019). Spark supports flexibility, while enhancing the processing efficiency. Spark processing produces semi-structured energy data that are storable in HBase. Apache Spark was employed as a distributed data processing engine for real time energy batch analytics. Spark supports fast, computations, in-memory iterative and has been proven to outperform conventional Hadoop MapReduce platforms in processing real time data. It also provides intuitive programming processes such as SparkQL for easy execution of big data analytics requirements (Simmhan et al., 2018).

Additionally, HDFS is used to store raw real time heterogenous energy data from MQTT topic (which are subscribed by prosumers and energy service providers see Figure 6) and HBase NoSQL database such as Apache Cassandra and CouchDB. Since energy data collected from metering devices and energy sensors are wrapped up in JSON format, this study opted for database that is flexible and efficient such as CouchDB. Accordingly, CouchDB was selected because it supports increased map-reduce for real-time energy processing, therefore results can be periodically viewed in CouchDB as the energy data increases. Similarly, CouchDB possesses a feature that enables periodic notifications, which allows external components to be informed in real time based on documents change (Cheng et al., 2015). In the context of this study CouchDB helps to manage both real-time and historical energy data as seen in Figure 7 acting as both storage device that saves processed energy data to serve external queries and subscriptions to push out data for prosumers, energy services providers, and stakeholders. This enables data space layer to decrease latency and complexity for RESTful APIs in application layers to provide real-time energy data.

Thus, HBase NoSQL database and CouchDB are utilized to store the processed energy data for energy market trading forecasting and prediction analytics to be utilized by prosumers and energy service providers in making decision regarding energy trading in energy districts. Also, CouchDB is used to store energy data that can be converted into action information in the application layer to provides interoperability open energy data to prosumers, energy service providers, and stakeholder via RESTful API to support energy trading in energy districts. Likewise, Apache Cassandra a NoSQL database is utilized as a datastore to elastically organize linked meta-data in a system. It has a linear scalability and has been proven to be fault-tolerance making it a viable database for organizing critical data in RDF format (Khan et al., 2013). Cassandra’s data model employs column-based schema and robust built-in caching that help prosumers and energy service providers in attainment the quality of service in exploiting energy data for achieving positive energy block in energy district.

3.4.7. Data Sources Layer

This layer constitutes the integration of software and hardware energy sensors, metering devices, appliances, EVs, etc. that provides real-time data in energy district (Khan et al., 2014), which are necessary for energy prosumption operations. This layer comprises of communication networks technology used by the energy devices to connect and transmit data to data platforms and includes provisions for specifying sensor metadata, both for existing and new sensors and can thus provide the necessary building blocks for acquiring contextual information about the sensors (Khan et al., 2014). Data from these energy devices entails their status (OFF or ON) and their parameters required to be sensed and sent to the technology layers for further processing. Therefore, data source layer includes sensors and actuators which generate large amounts of data via publish/subscribe by MQTT communication protocols aggregated in XML/JSON format conveyed into non-relational database repositories (HDFS) for further processing (Mokhtari et al., 2019). In this layer the coverage aspect of energy devices connects via different communication technologies such as those that provide comparatively short-range coverage (Bluetooth, Wi-Fi, Zigbee, Wireless Sensor Networks (WSN), Radio-frequency identification (RFID), etc.)) and those that provide wider coverage (3G, 4G long-term evolution (LTE), 5G, IEEE 802.15.4 low-power wide area networks (LP-WAN), LoRaWAN, etc.) (Simmhan et al., 2018; Silva et al., 2018).

4. Discussion and Implications

The discussions regarding the layered architecture, theoretical and practical implications are presented to show the significance of the study.

4.1. Discussion

Due to increased use of diverse sensor and metering devices developed by different vendors, energy prosumption services are faced with issues related to interoperability, processing and storage of heterogenous data produced in smart city. Although, prior studies have attempted to resolve the issues in sectors such as in mobility, energy, (see Table 1) by deploy RESTful API over HTTP and MQTT protocol. However, these studies lack efficient data handling features in multi-functional environments such as in energy districts where data are generated mainly from diverse metering devices and energy sensors. In such situation, data interoperability of these energy devices with dissimilar communication technologies cannot be easily supported. Thus, there is need for an architecture to process and analyze unbounded energy data relating to energy consumed and produced in smart city by prosumers, energy service providers, and other stake holders.

Therefore, this study contributes to the literature on sustainable energy prosumption and data services by developing a layered architecture that employs MQTT and HTTP via RESTful APIs for interoperability of real-time, online, and historical energy data for district energy management towards providing energy information in facilitating prosumption operations. Moreover, findings from this study aims to improve energy management at neighborhood level in achieving a positive energy district and increased energy trading based on the interaction and integration of district energy provider, energy prosumers, local energy marketer and city municipality. In addition, findings from this research presents the applicability of smart grid to support the bidirectional flow of electric energy and data flow to all entities, involved in the consumption and production of energy in smart city creating an energy value chain (see Figure 3-4). Moreover, findings from this study provides a roadmap for future studies on energy prosumption to explore the significance of local energy markets to enable positive energy block at neighborhood level.

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4.2. Theoretical and Practical Implications

Theoretically, the developed architecture provides a common standard for data format and exchange approach based on RESTful APIs to provide a common energy data environment in energy district to foster interoperability of energy services from different businesses involves in energy prosumption services and energy trading in smart cities. Hence, the layered architecture is embedded with MapReduce and Apache Spark big data tools for processing streaming real-time, online, historical energy data to allow manageability and accessibility of energy data using RESTFul APIs for intelligent decision-making. Then again, the layered architecture can be employed to exploit published, integrated, private, open, static, online and real-time data to improve other services in smart city such as in smart mobility.

Additionally, the architecture provides energy data-driven services in standard XML, CSV, and JSON data format with pre-defined RESTful APIs for interoperability data access, creating a shared data eco-system environment which is lacking in prior conventional energy driven architecture. Similarly, the architecture uses RESTful APIs as web service method that enables business to easily deploy their web service through HTTP protocol to aggregates and enriches energy data in making data available for prosumers to improve energy trading. Practically, the developed layered architecture exposes energy data in silos to third-party applications so that such data can be exploited by energy prosumers and energy service providers to improve energy trading. For example, data related to citizens energy consumption owned by energy service provider is made open via RESTful API in the architecture to be shared to prosumers in a district to support in measuring and predicting energy demand load and usage behavior within a district.

Besides, the data can be employed by prosumers and other stakeholders for the development of innovative energy prosumption solutions. The layer architecture facilitates openness and discovery of energy data among prosumers and enterprises in order to foster sustainable energy prosumption by enabling the energy data capturing, filtering, processing, analyses and saving of energy related data. Hence, the architecture can be deployed to provide shared data-driven services to develop an integrated energy system for optimized vehicle to smart grid and vehicle to residential building energy exchange in actualizing a sustainable energy district facilitated by big data technologies and solutions. This will allow renewable energy production and exchange between EVs, buildings and optimization of the local energy consumption linked to the smart grid. The architecture further depicts the role of prosumers, municipality, energy server provider, distributors or operators in participating actively on the energy market or as energy brokers to trade and enable energy flexibility via energy data exploited and combined to be used by different applications and services.

5. Conclusion

Evidently the topic of energy prosumption in smart cities is gaining significance in the global context. The fact that urban population is expected to increase in the coming years leads to the assumption that there will be increase in energy demand. This increase will lead to negative environmental impact since majority of energy consumed in cities are derived from non-renewable sources. One possible solution is citizens as prosumers generating and consuming energy from renewable sources such as solar and usage of EVs to reduce CO_2 emission. Although, prosumption services produce and utilize energy related data which is to be shared among different prosumers, energy service provider, and stakeholders. Obviously, there is a need for an approach that would enable the sharing and utilization of such heterogenous data thereby processing, analyzing, and managing it as openly available data to support the interoperability with a variability of protocols to collect and transmit data among energy devices has given rise to interoperability issue in smart cities in managing heterogenous data produced by metering devices and energy sensors.

In this paper we developed a layered architecture that integrates MQTT for managing real-time, and HTTP RESTful APIs for online and historical data of energy data in the context of residential buildings and EVs towards providing energy data to support decision making in facilitating prosumption of energy via renewable source (solar PV) to better improve energy prosumption in smart grid. The layered architecture holistic integrate seven different layers based on APIs to provide new energy services such as detailed and real-time information monitoring about energy prosumption, forecasting in the community via applications to support decisions in terms of energy decrease investment, planning to attain positive energy district and increase renewable energy trading. However, the developed layered architecture was not empirically tested using real case data from a smart city district. Thus, ongoing work involves adopting a proper research methodology e.g. design science research to validate each layer of the architecture based on real qualitative case data from two energy companies located in Norway to test the applicability of the architecture in relation to the company's current practice in achieving a sustainable energy source.

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