DIGITAL TWIN SOLUTION IMPLEMENTED ON ENERGY HUB TO FOSTER SUSTAINABLE SMART ENERGY CITY, CASE STUDY OF SUSTAINABLE SMART ENERGY HUB

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ABSTRACT:

The scarcity of energy is one of humanity's most pressing issues in the twenty-first century. These problems can be found in various areas, including energy supply, exchange, and consumption. Population growth, rising global energy demand, natural resource shortages, and environmental concerns contribute to energy scarcity. Furthermore, energy shortage needs the expansion of renewable energies and energy efficiency, a major concern for all governments and organisations. Building energy efficiency is a crucial concept to consider when it comes to smart cities. Buildings are the greatest energy consumers, accounting for 40% of total energy consumption. Recent advances in machine learning within a big data context have paved the way for more efficient building energy management. Building energy consumption may be successfully managed by a real-time measurement procedure, allowing the economy to shift from a linear to a circular consumption model. This will tackle the issue of late notice of failed energy-saving initiatives and allow for immediate correction to restore the energy management system to ultimate performance.

The energy hub might be as small as a single home energy system or as large as an energy system for the city. This paper will present a case study on developing a smart energy hub called Hubgrade 4.0 that relies on connected products using digital twin as a significant enabler for energy-saving initiatives. Hubgrade 4.0 provides an innovative approach to successfully implementing energy efficiency improvement using artificial intelligence and real-time data. Hubgrade 4.0 is the name of Enova by Veolia smart energy hub; Enova is the regional leader in integrated energy and multi-technical services, delivering performance-based energy and facilities management solutions. The energy hub digital twin is a link between a physical platform that administers the energy hub's IoT and a virtual platform that can derive services that are valid for the energy hub. Successful enterprises are using several new technologies to achieve the goals of Industry 4.0: efficiency, speed, agility, and customer-centricity. This paper concluded and highlighted lessons learned from the successful implementation of innovative energy management, which relied on a dedicated organisation, effective adoption of digital technologies, and embracing new business models, resulting in power savings of 254 million kW and water savings of around 3 million cubic meters, as well as financial savings of about 138 million AED in 5 years since Hubgrade 4.0 started operations its first energy-saving contract in 2017.

1 . INTRODUCTION

Cities consume 78 percent of global energy and produce 60 percent of global greenhouse gas emissions, while they only cover 2% of the earth's surface area (UN, Cities& Pollution 2018). The environmental impact of urbanisation will increase as the world's population grows from 55 percent to 66 percent by 2050 (UN, World Organization Prospects, 2018). Improving municipal resource efficiency would result in more environmentally sustainable solutions and assist in the transition to a more sustainable future.

A stable, efficient, and low-carbon energy supply is one of the most crucial requirements for next-generation smart cities (Edward et al., 2019).

The concept of a smart city has gained popularity in recent years due to its use of digital technologies to improve service delivery and energy efficiency. Different sensors are utilised in smart cities to acquire digitised data and offer information that is then used to manage systems and optimise asset performance. Traffic systems, energy supply, water distribution networks, waste collection, law enforcement agencies, information systems, residential communities, shopping malls, commercial buildings, hospitals, airports, and other community services are all monitored and managed using data about equipment, buildings, people, and various types of assets (Sanguk et al., 2019).

A smart energy city optimises energy usage, has a well-planned energy management system and accurately records energy-

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saving accomplishments. For example, the sustainable smart energy city (SSEC) concept (Nielsen et al., 2013) aims to deliver comfort, energy savings, and welfare to its residents by employing modern technology to improve energy management systems. (Sanguk et al.,2019).

This appeal to construct a sustainable smart energy infrastructure within the city will allow for continual improvements in energy consumption, safe and enjoyable living, and a smart infrastructure-based metropolis that is both quick and cost-effective. (Shahidehpour et al., 2018)

The long-term survival of a smart energy city depends on the rational and systematic deployment of technologies and a thorough analysis of all the city's assets. Therefore, sustainability in the energy industry refers to the efficient use of energy in general and the development and deployment of innovative technology to support efficient operations (Park et al., 2016).

Digital Twins are the most advanced and comprehensive way to monitor and optimally manage a complex system like the upcoming solutions, representing the energy sector's future. These will include a variety of energy generators, both traditional and renewable energy sources (M. Lamagna et al., 2021).

Micheal Grieves' concept of a digital twin echoes this concept, which is critical to the future energy system (Grieves and Vickers,2017). According to Grieves, the DT system is founded on three notions: physical items in real space, virtual products in virtual space, and data and information linkages that connect the physical and virtual environment (Barricelli et al., 2019).

DT is an important component in improving energy system efficiency and management. For example, working with energy on a transmission grid or a household system necessitates quick responses and analysis.

2. LITERATURE REVIEW

Traditional energy supply systems (for example, electricity networks) have a hierarchical structure that is primarily responsible for an energy carrier's generation, transmission, scheduling, and administration (Geidl et al., 2007).

As a result, an energy hub's key benefit is the efficient utilisation of multi-generation (co, tri, or poly-generation) systems to maximise energy efficiency while lowering emissions and costs. (Mohammadi et al., 2017).

Synergies between various forms of energy provide a significant opportunity for system improvement. Aside from the capabilities of modern information technology, state-of-the-art and emerging and looming energy technologies, such as fuel cells, are taken into account

By optimising and transitioning between multiple technologies to meet energy usage, the energy hub has a good chance of reducing energy consumption. As a result, the energy hub can also better use resources, increase efficiency, lower costs, and reduce carbon emissions. (Mohammadi et al., 2017).

Energy hubs can be used for various purposes, including residential, commercial, and industrial buildings such as shopping malls, housing complexes, educational complexes, hospitals, hotels, small and large factories, airports, and even individual residential or office buildings. In addition, they can be used for a small geographical area or a city. The energy hub can be any size; it could be a single residential unit, a shopping mall, or the entire city.

The ability of the digital model to modify its parameters always to be updated and mirror the real system is priceless (M.Lamagna et al., 2019).

Building energy benchmarking is a traditional method of conducting large-scale building portfolio analyses. However, such measures are ineffective in identifying specific efficiency opportunities or supporting real-time energy management. The accessibility of data from smart meters across a community. (A. Francisco et al., 2019).

Benchmark energy consumption over time and found that a digital twin enabled energy management platform that creates temporally segmented building energy benchmarks can help detect previously unseen insights and identify more specific time-driven strategies for near-real-time urban energy management. (A. Francisco et al., 2019)

Smart city digital twins, a recent effort to develop a digital replica of city infrastructure linked to real-time city data, are intended to improve city monitoring, control, and decision-making through improved visualisation and interaction with city data (Mohammadi and Taylor, 2017).

Given the growing availability of building performance data at urban scales, smart city digital twins could be a potential platform for building portfolio performance assessment and urban energy management (i.e., digital twin–enabled energy management). (A. Francisco et al., 2019).

At the same time, measures aimed at making cities more sustainable and energy efficient are becoming increasingly prevalent. By 2050, nearly 180 cities, counties, and two states in the United States have pledged to use all of their energy from renewable sources (Sierra Club, 2019).

Other laws, such as building benchmarking legislation requirements, demand the public sharing of whole-building energy consumption and production data for individual buildings at community and municipal scales (e.g., Building Rating 2019; Building Rating 2020).

To meet greenhouse gas emission reduction pledges (Zuo et al., 2013) and strive toward digital twin–enabled smart city energy management, harnessing the potential of such data, made available through substantial investments in smart infrastructure, is crucial.

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2.1 Smart Energy Hub and smart cities

The Smart city concepts have received a lot of attention in recent years due to their use of advances in information and communication technology to improve the quality and efficiency of services and resources. Microgrids have the potential to be very helpful in the development of smart cities. (Shahzad et al., 2018).

The Smart City concept aims to improve the quality of services given to citizens while cutting government operational costs. (Alexandra et al., 2015).

The Energy Hub is a strong concept for gathering, converting, and distributing energy resources in the smart city. The term "smart grid" refers to how power networks are getting smarter and more automated. Smart grids can retain data, interact, and make decisions in addition to the normal network tasks of power production, transmission, and distribution (Mohammadi et al., 2017).

To build, optimise, and improve the operation of energy network infrastructures, smart grids employ advanced applications and communication, digital information, and automated monitoring technologies. As a result, smart grids improve demand-supply efficiency and make better use of existing infrastructure, decreasing the need for new infrastructure development. On the other hand, smart grids make it easier to integrate renewable energy sources on the demand side, especially in the form of distributed generating (Maria and Michael, 2016).

Increasing resource efficiency at the city level would allow for more ecologically friendly solutions and aid in the transition to a low-carbon economy while also addressing the challenges of rapidly rising populations in such areas. Several UN, EU, and US projects to discover solutions for such sustainable cities have lately been initiated. The Global Initiative for Resource Efficient Cities (GI-REC) of the United Nations, the European Union's European Innovation Partnership on Smart Cities and Communities (EIP-SCC), and the United States Smart Cities Initiative are among them (Edward et al., 2019).

However, the smart grid concept emerges as power networks become more sophisticated and automated. Despite the widespread use of the phrase "smart grid" in the literature, there is no definitive or comprehensive definition.

The smart grid is a modern power system that improves efficiency and reliability by utilising autonomous control of information and communication technology and energy management infrastructures. (Kolokotsa, 2015).

The smart grid is looking for a combination of these technologies that will allow it to establish a self-healing and more dependable network. In addition, smart grids increase supply efficiency by maximising the use of existing infrastructure, decreasing the need for system development, and allowing renewable energy sources to be integrated (Kolokotsa, 2015).

On the consumer side, this involves making better use of existing infrastructure, decreasing the need for system development, and making it easier to integrate renewable energy systems, particularly distributed generation.

Adopting smart meters and communication technologies, as well as two-way communication and information technologies, is the first step toward creating a smart grid. These technologies will provide tools for predicting various parameters and managing them appropriately. For example, these technologies' data can anticipate temperature, humidity, and sun radiation and provide two-way communication.

The two-way communication technique can supply real-time data and a real-time monitoring system that can fix errors and make real-time modifications for optimal energy efficiency (Konark and Lalit, 2015).

A sustainable smart energy city includes smart energy, smart meters, smart houses, buildings, factories, smart grids, and electric transportation.

2.2 Digital twin implementation in Smart Energy Hub

Integration of information and communication technologies plays an increasingly essential role in designing smart cities and developing digital strategies to address social, economic, environmental, and safety challenges.

The ability to address and handle new emergent difficulties is required for such digital transitions to succeed. (Grieve, 2017). The global implications of urbanisation and the growth of human activities are increasingly creating deep interconnections between humans, infrastructures, and technologies over time.

The use of Industry 4.0 principles in the configuration of city digital twins provides a big leap forward for urban sustainability from design to building and maintenance (Zheng, 2019). It is defined as a digital replica of a physical asset that collects data from sensors, drones, or other sensitive IoT devices and uses advanced analytics, machine learning (ML), and artificial intelligence (AI) to gather real-time processed data about the lifespan process of physical assets. (Sofia et al., 2021).

Building energy benchmarking, often done annually (Borgstein et al., 2016), is a traditional technique for completing large-scale building portfolio analyses.

Such measures, on the other hand, provide little information about specific efficiency opportunities to target or enable real-time energy management. The availability of smart meter data across a community of buildings allows for the creation of building energy benchmarks, which are benchmarks produced at finer temporal scales and throughout specified time segments.

If they can provide more insights, value, and frequent feedback than their annual counterparts, energy benchmarks split by time have tremendous potential to improve the efficacy of digital twin–enabled energy management solutions and the energy hub concept.

The development of dynamic and real-time measurements that translate smart meter data into valuable information is critical to the success of the digital twin energy hub. Managers can identify and prioritise specific retrofit methods and detect near-real-time variations in building efficiency in the context of the entire building portfolio using a smart city digital twin energy hub based on building energy benchmarks (A. Francisco, 2019).

3. RESEARCH METHODOLOGY

Using Hubgrade 4.0 as a case study for Energy Hub provides in-depth analysis to support the research argument. The practice of energy hubs and energy management methods is extremely established in the UAE; readings obtained from electricity sub-meters from different types of facilities (residential, commercial and industrial) are examined by energy specialists in Hubgrade 4.0, and then the results are visualised using developed software, then these results combined in macro energy dashboard. Data was gathered during site visits to Enova's Energy Hub to meet with energy specialists and discuss data processing, analytical reports, and how energy specialists visualise these data on the Hubgrade 4.0.

Due to a scarcity of success stories from completed case studies, there are chances to optimise energy use that have been neglected. Even though numerous opportunities exist to save energy and optimise energy consumption in existing buildings, these opportunities have been overlooked due to building owners' unwillingness to embrace energy-saving measures.

4. HUBGRADE 4.0 - A CASE STUDY OF SMART ENERGY HUB IMPLEMENTING DIGITAL TWIN FOR ENERGY BENCHMARK

Many countries combine bespoke services and businesses within their energy infrastructure and urban environments to create sustainable smart energy cities worldwide. As a result of these changes, the development of a Smart Energy Hub might be hastened, bringing people benefits such as convenience, safety, and cost savings.

A Sustainable Smart City employs a variety of sensors to collect electronic data and provide information that can be used to manage assets and resources effectively. For example, traffic and transportation systems, power plants, water supply networks, waste management, law enforcement agencies, information systems, schools, libraries, hospitals, and other community services are all monitored and managed using data about residents, devices, and assets. (Sanguk et al., 2019).

Hubgrade 4.0, a new energy hub created by Enova by Veolia in 2014, monitors and optimises real-time energy, water, and material flows. This centre processes real-time data to help municipal, commercial, and industrial clients better manage their resources.

Enova by Veolia is a regional leader in integrated energy and multi-technical services, offering its clients comprehensive and performance-based Energy and Facilities Management solutions to help them achieve their financial, operational, and environmental targets.

The Hubgrade 4.0 dashboard collects real-time data from linked sensors and submeters in buildings and services, compares it to benchmark readings, and provides analysed feedback to the Operations team so they may tune up running equipment.

The data is then presented to operational teams on the ground in a reporting dashboard system that presents the most important and relevant information from digital systems for quick decision-making and performance metrics. In addition, Hubgrade 4.0 provides customers with online access to reports and information to improve end-user awareness.

The dashboard in Figure 4 displays real-time data collected by installed sensors and submeters for evaluating energy use for one of the shopping centres (electricity & water).

These data will be compared to the baseline by comparing actual energy consumption readings to the baseline; this will provide a continuous monitoring mechanism, as if energy consumption exceeds the baseline, a red sign will appear, alerting the operator to check asset performance and bring energy consumption to a positive magnitude; the legend below represents the alarms that appeared in monitoring mechanisms

4.2 Using Digital twin application to benchmark building energy consumption

Enova's Hubgrade team uses a Digital twin application for modelling the virtual environment of the existing building to simulate energy consumption and create a baseline to optimise air-conditioning system operations by comparing the simulated data with existing data to identify energy-saving measures as in Figure 1

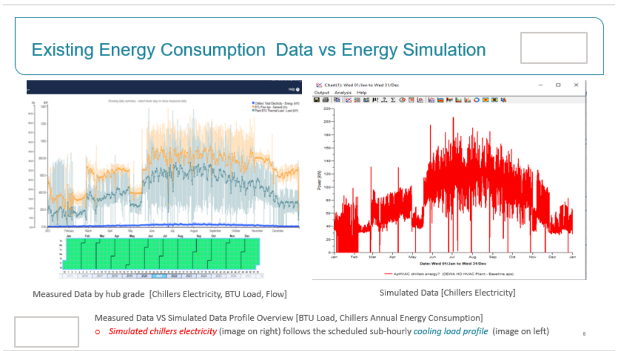

Figure 1: Existing data consumption vs Energy simulation

The comparison between current and simulated energy consumption shows the opportunity to implement energy-saving measures and optimise energy consumption by around 2.8% electricity savings, as in Figure 2.

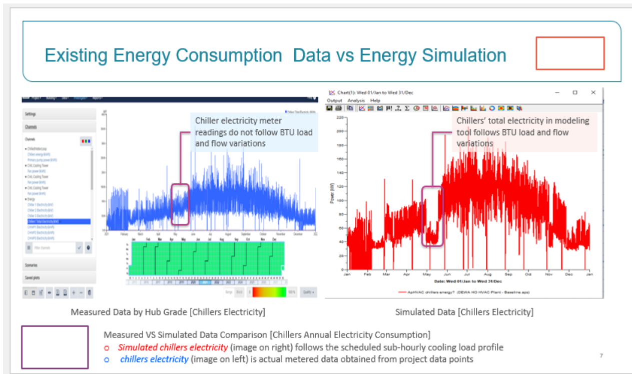

Figure 2: The simulation shows that the chillers do not modulate with varying chilled water flow and Load.

4.3 Energy optimisation in Hubgrade 4.0 model

The dashboard shown in Figure 3 shows real-time data for one of the shopping centres collected by installed sensors and submeters for measuring energy consumption (electricity & water).

Facility	Utility	<A	A<B	B<C	C<
Shop.Cent1	electricity	<3.85%	3.85%<7.7%	7.7%<10%	10%<
Shop.Cent1	Water	<2%	2%<7.28%	3%<4%	4%<
Shop.Cent2	electricity	<3.69%	3.69%<7.38%	7.38%<10%	10%<
Shop.Cent2	Water	<3%	3%<4%	4%<5%	5%<
Shop.Cent3	electricity	<3.17%	3.17%<6.34%	6.34% <10%	10%<
Shop.Cent3	Water	<5%	5%<6%	6%<7%	7%<

Table 1: Monitoring Mechanism Dashboard

These data will be examined against the baseline by making the comparison between actual energy consumption readings and the baseline; this will provide a continuous monitoring mechanism, as in case energy consumption is more than the baseline energy consumption, the red sign will appear, giving an alarm to the operator to check the asset performance and bring energy consumption to positive magnitude, below is the legend represent the alarms appeared in monitoring mechanism dashboard to ensure proper monitoring of energy optimisation process:

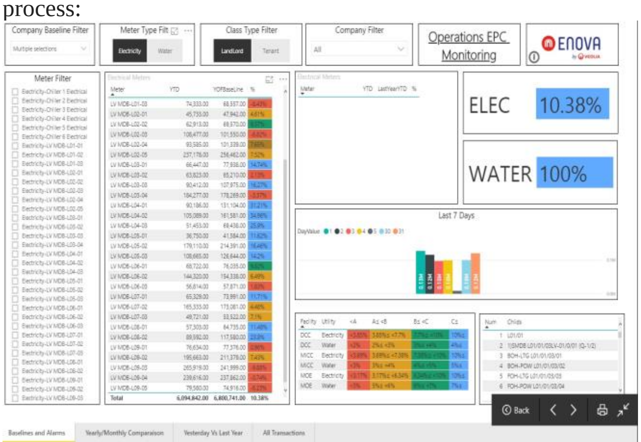

Figure 3: Dashboard showing Metering system readings in one of the shopping centres.

Then in Hubgrade 4.0, the energy team will analyse collected data and summarise the results as shown in Figure 4 and then use developed software and IoT technology to show total saved electricity in terms of KW, the dashboard showing saving electricity of 1,436,375 KW, which is equivalent to 617,641 AED and saved water 18,251M3 equivalent to 208,794 AED.

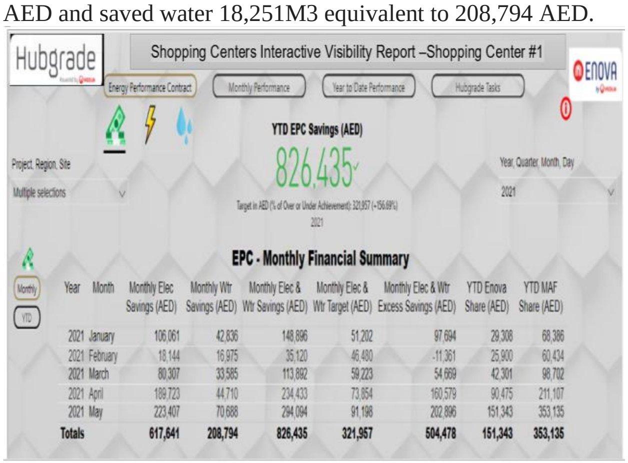

Figure 4: Summary of energy consumption results for selected shopping centres

In Figure 5, we may consider the dashboard as a micro-energy hub dashboard representing energy optimisation for shopping centres at the micro-level, where clients and service providers can monitor the progress of building system energy optimisation plans.

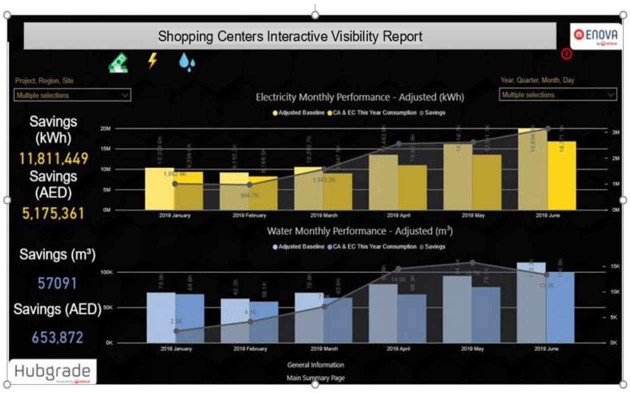

Figure 5: Dashboard for energy optimisation results for shopping centres as a model for Micro Energy Hub

4.4 Hubgrade 4.0 model for renewable energy

The integration of renewable energy in Hubgrade 4.0, as shown in Figure 6, will help the implementation of microgrids, develop the implementation of sustainable smart energy cities, support the increasing demand for power, and reduce carbon footprint. The dashboard for a solar system for all shopping centres connected to solar system submeters sends energy-generated readings in real time to Hubgrade 4.0, compared with targeted values set by the energy team to monitor solar system performance. The solar dashboard reports 4.9Mil KW generated from solar grid installed in shopping centres from Jan 2021 till June 2021, achieving 48% of the yearly target.

Figure 6: Solar Energy generation Dashboard for shopping centres

4.5 Hubgrade 4.0 model - Sustainability report

The sustainability report shown in Figure 7 represents a summary report for all energy optimisation activities monitored by Hubgrade 4.0; it acts as a Macro energy hub dashboard for all projects controlled by Hubgrade.

It represents the integration of several micro hubs like residential buildings, hotels, shopping centres, and others under the control of a Macro energy hub, which gives financial, economic, and technical benefits and increases the contribution of preserving the environment protect the environment.

To summarise the results of energy optimisation in all projects as visualised in the sustainability report, Hubgrade 4.0 was able to save 254 million kW of power and around 3 million cubic meters of water and give a financial saving of about 138 million AED.

These results are encouraging results to motivate public and private sectors to adopt energy-saving and energy management to benefit from efficient usage of energy and push authorities to adopt solid policies to move the community to more efficient power consumption as Jaffi and Stain argue that Each kilowatt of energy of plant capacity reduced to save the city more than the individual who decides to save energy (Jaffi and Stain, 1994).

Applying the Hubgrade 4.0 concept on the city level that adopts efficient energy consumption and promotes a developed energy management system that can link different kinds of micro energy hubs using smart digital technologies will create a sustainable smart energy city.

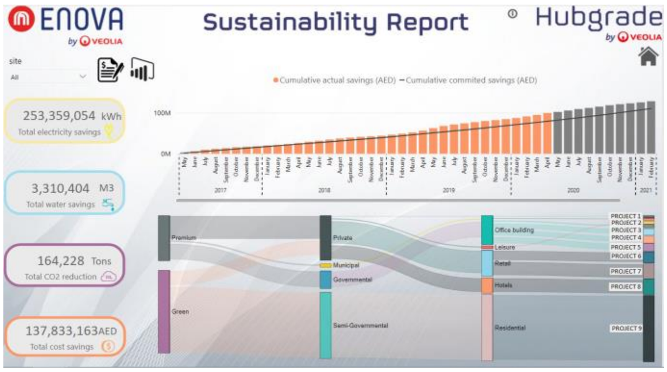

Figure 7: Comprehensive Macro Dashboard for different types of buildings, including residential, commercial, and industrial

5. FINDINGS AND DISCUSSIONS

The research and case study reveal that the impact of the increased population on earth requires huge efforts to customise the consumption of natural resources; the optimal use of these resources requires a centralised monitoring system and integrated energy management.

Introducing Energy hub as a concept provides a powerful tool to manage energy flow and monitor energy consumption in real-time utilising new technologies and IoT, providing required data to the energy hub dashboard to visualise the results of optimising energy consumption and minimise carbon footprint.

Applying the energy hub concept to the city level introduces two types of an energy hub. First, one micro hub and 2nd is macro hub depending on the type of facilities and consumer and consumption pattern; the micro-energy hub can be residential, or commercial or industrial, while macro hub can integrate several types of micro hubs, moving toward smart energy system with developed new technologies evolving energy. Management to be smarter and smarter towered machine learning and digital twin to reach to optimal use of energy resources.

Hubgrade 4.0 case study shows the benefits of employing energy hub on micro level and macro level leverage the huge amount of data and visualising the results on smart dashboards allowing operator and the client to take the right decision. It is a good model for creating a sustainable smart city that optimises its recourses.

6. CONCLUSIONS AND FURTHER RESEARCH

To create a sustainable smart energy city, combining and customising several services and businesses within the structure of energy systems and city infrastructure is essential.

A healthy society that uses smart technologies to manage a collection of smart city infrastructures that support sociotechnical and socioeconomic initiatives and celebrate cultural and ethnic diversity, for example, could play a key role in organising the global response to challenges posed by rapid urbanisation (Shahidehpour, 2018).

The DT-based real-time monitoring results can reduce the gap between the energy performance of the buildings (simulated through energy diagnosis) and the real building performance. This is possible thanks to data analysis, which allows one to get more refined energy management strategies, even highlighting inadequate users' behaviours and policies.

DT is extremely transversal and applicable both to macro level and micro level scales (from district to apartment), as demonstrated for the use of energy management systems(Sofia et al., 2021).

Since an energy hub can integrate several services for different types of facilities, energy hub is an excellent solution to optimise energy consumption as an integrated energy management system; the micro-energy hub can be a great solution to remodelling of energy consumption of residential, commercial and industrial facilities while Macro energy hub can integrate several micro hubs giving the advantages of technical, economic and environments benefits. However, due to the large volume of data and connectivity with a large number of sensors, the use of IoT and smart technologies became essential to explore the results of energy system optimisation moving these facilities to be smarter and smarter.

The case study shows considerable energy savings and proof that optimising energy consumption in micro and macro levels utilising smart technologies and IoT, presenting these results through the smart dashboard is the first step towards a sustainable smart energy city.

Below in Figure 8 is a model of a future sustainable smart energy city where centralised macro energy hubs adopt different services; introducing new IoT and digital technologies will bring considerable energy savings besides minimising plans for new power plants.

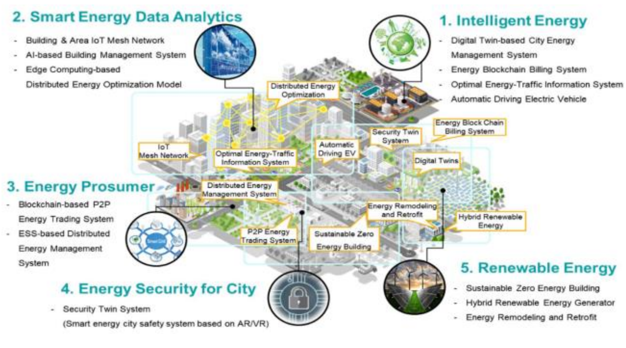

Figure 8: Future model for sustainable smart energy city (Sanguk et al. 2019).

Future plans require the intervention of governments to play a significant role in forming new policies, new regulations to incentivise and promote sustainable smart energy cities and smart energy hubs to encourage communities and building owners, businesses to adopt building micro hubs as part of city infrastructure and connect these micro hubs to centralised macro hubs Also, future studies should concentrate on the connectivity of all services using smart technologies creating digital twin model and building comprehensive smart energy hub controlled by city municipal as an urban twin model which deals with several services electricity, water supply, renewable energy, waste management, traffic, electric cars and city security system. (Kablan, 2004).

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