Review of Recent Works on Internet of Things-enabled Small-scale Wind energy Portable Turbines (IoT-SWEPT) for Wind Energy

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***Abstract*—In recent years, efforts to harness wind power worldwide have accelerated. Researchers identified locations for potential Wind farms (with sufficient outputs) near the northern coastal regions. However, assuming these wind farms were built and power was generated, this power still needs to be transmitted to the end-user through the electrical Grid. Due to the remote locations of these farms, and the very nature of Wind Power, integrating this power into the Grid becomes a challenge. An alternative source of Wind Power could be the world's vast network of superhighways and city roads. Recent studies in Malaysia showed that the annual aerodynamic energy loss of moving vehicles on Malaysian highways is estimated at 1.2 MTOE (Million Tons of Oil Equivalent, with 1 TOE = 11.63 MWh). In recent years, advances in Small-scale Wind energy Portable Turbines (SWEPT) have made them a viable option. Furthermore, the Internet of Things (IoT) could play a role in further enhancing these SWEPT units by connecting them to the cloud to enable remote monitoring and controlling. These IoT-SWEPT would allow developers and researchers to monitor deployed SWEPT units from anywhere and anytime, so long as they are connected and hold proper credentials. This paper reviews recent reports on these developments.**

Keywords*—Wind Power, Renewable Energy, Wind Power of Highways, Portable Wind Turbines

I. INTRODUCTION

In recent years, efforts to harness wind power have increased exponentially, with countries like China, US, Germany, Netherlands, and Spain taking the lead. Researchers realized that the first challenge to securing Wind Power is identifying ideal locations for the potential Wind farms and then setting up the farms to capture and deliver that energy to the end-user. Research shows that the ideal locations for such farms are often at remote locations, such as rural regions, beaches, hilltops, or even offshore. To identify and select the location, the researchers need to visit the potential location (In-Situ data collection) and collect the data regarding the wind properties.

Secondly, wind power depends on wind patterns, such as wind speeds, direction, and consistency. As a result, integrating the power generated from wind farms into the electrical Grid becomes a challenge [1-3].

However, there is an alternative source of Wind Power, the world's vast network of superhighways and city roads. Trucks, buses, trains, and other vehicles traveling fast on highways and roads generate winds in the areas very near to these roads. And these vehicle-generated winds are very real and could be translated into energy [4-6]. A recent study in Malaysia investigated precisely that. Researchers measured the aerodynamic energy created by moving vehicles and estimated the amount of energy lost (due to not being utilized) on Malaysian highways to be around 1.2 MTOE, or 1.2 Million Tons of Oil Equivalent, with 1 TOE = 11.63 MWh, that is a staggering 14 GWh [7].

On the other hand, research on Small-scale Wind energy Portable Turbines (SWEPTs) has also advanced in recent years. For example, developers created SWEPT units that can be installed onto moving vehicles and then be used to capture wind energy as the vehicle moved, with research focusing on balancing between efficiency and aerodynamics. This paper reports on these developments, as discussed below [8].

Among the main problems faced when setting up a wind farm is the lack of precise and accurate data on wind speed and direction from a particular location. Moreover, researchers must travel to remote places to gather the required data. Finally, not all potential areas for windfarm can be studied simultaneously because it needed more time to study and forecast the wind data on the actual location (In-Situ), especially for multiple potential areas [9].

These problems can be resolved by using the Internet of Things (IoT), by creating connected data-gathering devices that can measure wind speeds and directions and broadcast that information to the researchers, wherever they are, as long as they are connected. Using these devices, researchers can obtain and study real-time data from the comfort of their home labs or stations. For example, the data collected over a prolonged period can be used in addition to meteorological data to verify if a particular place has the potential to set up a wind farm there [10].

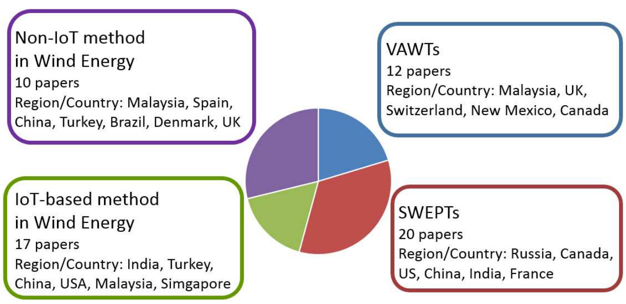

Fig. 1. Outline of Reviewed Topic

Figure 1 shows the outline and overview of this review paper, showing the numbers of reviewed articles, related regions, and countries based on the topics. This paper reviews recent reports related to these issues, specifically on the potential of highways & city roads as a viable source of Wind Energy.

Secondly, on the design and development of Small-scale Wind energy Portable Turbines (SWEPT) units. Finally, current trends and practices in implementing the Internet of Things (IoT) and other technologies (Non-IoT) for renewable energy in general and wind energy in particular.

These reviews include technological solutions, surveys and studies, and proposals for implementing IoT effectively for wind energy generation.

II. Ease of Use Highways and city roads as a source of Wind Power

Vertical Axis Wind Turbines (VAWTs) are a promising technology to capture power from these vehicle-generated winds. Placed directly on the road, power generated from VAWTs can be used to power lights, traffic signals, emergency equipment, and guiding signs and can also be used for future technologies such as IoT-based smart roads and infrastructure [11]. Developing effective VAWTs is not the primary challenge; the technology behind VAWTs is well established and available. Instead, the main challenge is often identifying the ideal locations (along the roads and highways) to install the VAWTs for maximum power generation [12-14]. The challenge can be mitigated with C-VAWTs, Connected VAWTs, or VAWTs that are linked to the cloud via the Internet of Things (IoT). C-VAWTs can then be deployed in potential locations, left to operate with minimal on-site supervision while being remotely monitored. As a result, the process of identifying ideal locations becomes more efficient and cost-effective [15].

The vertical axis wind turbines can be configured in two ways. The Savonius and Darrieus wind turbine. Savonius wind turbine is simple to construct, looks better than a traditional wind turbine, and is easy to maintain. However, the speed is restricted. As a result, they are not very popular on a large scale. This type, on the other hand, can be beneficial for small-scale projects. It has low efficiency and is drag-driven [16-19]. The Darrieus wind turbine, on the other hand, can reach high speeds and is thus popular among large-scale energy producers. However, it is not simple and comes in three different shapes: oval-shape rotor, H-rotor, and spiral type. In addition, it is high-efficiency lift-driven [20]. There has been significant research on large-scale vertical axis wind turbine (VAWTs) installations in the United States and Canada since the 1970s and 1980s. However, their applications were gradually halted due to falling fossil fuel prices. In addition, because of significant investments made by many countries over the last 20 years, most large-scale wind turbines installed today are horizontal-axis wind turbines (HAWTs), which has slowed the progress of VAWT technology [21].

However, environmental concerns and energy security concerns in an urban environment have recently been renewed interest in various types of VAWTs. Vertical axis wind turbines (VAWTs) are simple to install, have low noise levels, and are environmentally friendly urban applications. Furthermore, as the number of passing vehicles increased, the smart VAWTs rotated effectively [22]. Table 1 below summarizes the discussion on VAWTs, C-VAWTs, and the type of vertical wind turbine.

Table 1 Summary of VAWTs

Vertical Axis Wind Turbines (VAWTs)	
Technology	Purpose
C-VAWTs	To monitor and identify the potential wind energy location using the IoT platform
Savonius wind turbine	For small-scale projects, less complexity
Darrieus wind turbine	Large-scale energy production

III. Small-scale Wind energy Portable Turbines (SWEPTs)

Rather than capturing wind energy from the side of the road, researchers realized they could use the Small-scale Wind energy Portable Turbines (SWEPTs), we can capture energy onboard moving vehicles directly [23-25]. Power output is proportional to the square of the radius of the wind turbine and the cube of the wind velocity. Researchers realized that, as the size of the wind turbine and the wind speed decreases, the power decreases drastically. They also identified Structural factors such as modularity, reliability, and cost play vital roles in the design of SWEPTs [26-28]. Researchers also implemented computational frameworks to evaluate the aerodynamics and aero-acoustics of SWEPT units to ensure a balance between aerodynamic fluency & maximized output [29]. The aerodynamic performance and the aerodynamic acoustics of full-scale horizontal-axis wind turbines were further investigated. Based on these analyses, researchers concluded that the wind turbine operations on moving vehicles could be optimized by adjusting the rotating speed according to the inflow wind velocity [30].

These conclusions were based on the simulation frameworks they implemented, namely, the Large Eddy-Simulation (LES) for dynamic rotations near the wake of horizontal-axis wind turbines under turbulent inflow and the Ffowcs Williams-Hawkings (FW-H) framework was utilized for the aero-acoustic calculations [31]. Some researchers have built working prototypes of SWEPTs, such as the wind turbine-driven generator [32] and the portable wind power apparatus for recharging batteries [33], a sketch of which is shown in Figure 2. These efforts combine mechanical and automotive engineering design elements. SWEPT units can be mounted on the roof of vehicles. As the car moves forward, a current of air flows through the inlet where the wind turbines and blades are housed, causing them to rotate, driving electrical generators and creating electricity [34].

This power is then stored in onboard batteries, which can be utilized for any purpose, whether for the car itself or at home. Furthermore, with the development of electric or hybrid vehicles, this design could be ideal for charging the car's batteries, thus extending the mileage and efficiency [35].

It relates to a wind turbine augmented by a diffuser for driving a generator of electricity in particular to such a turbine wherein an element of the diffuser can be folded to reduce the diffuser's size and limit charging by the generator under very high wind conditions. As seen in the patent design, a turbine may be augmented by a diffuser. The diffuser is a duct that produces deceleration of the moving fluid, such as the moving air, resulting in increased fluid pressure. The combination of a diffuser with a turbine increases the effectiveness of the turbine by allowing it to extract more power from the air incident upon the turbine [36, 37].

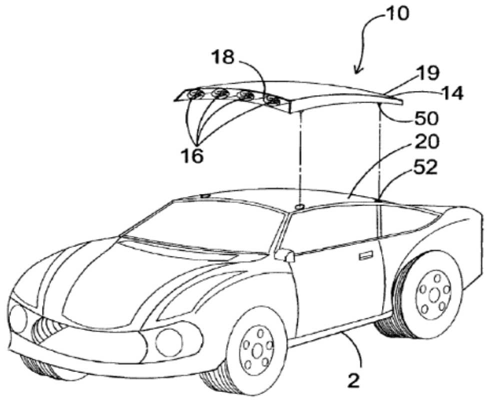

Fig. 2. Portable Wind Turbine Mounted on Vehicle [33]

Another SWEPT consisted of a portable wind turbine generator that is provided with a battery cartridge and the cartridge line, the battery cartridge and the connecting shaft threaded connection, the connection shaft surface is provided with a thread, is a telescopic structure, the overall height of the apparatus can be adjusted. While the box and connecting rod threaded connection, can be disassembled, the entire apparatus can be detached from the connecting rod at the top and bottom of the battery cartridge according to the actual situation, portable installation, the battery cartridge, the cartridge line, the connecting rod, and the equipment case communicate with each other, to facilitate erection and installation; easy removal of the present invention is mounted while the portable for fieldwork [38].

It is commonly known that traditionally, a wind turbine has a single rotor to capture kinetic energy. This dual rotor wind turbine was introduced to maximize the harvesting of all available wind energy. This idea was suggested because the airstream after the first rotor on a wind turbine is moving slower than the airstream.

Therefore, the wind airstream is wider after the first rotor, and the second rotor can harvest the excess wind flow after the flow. The gap of this dual rotor wind turbine is not to be seen many in any wind farms around the world. Hence, it would be a good design concept, and also, the efficiency of this dual rotor of the wind turbine can be validated in modern computer-aided software such as Solidworks and PTC Creo [39- 42].

The discussion on SWEPTs in this part is summarized in Table 2, mentioning a few kinds of research on a small-scale portable wind turbine.

Table 2 Summary of research on SWEPTs

SWEPTs related research	
Research	Output/purpose
Swept utilization	SWEPT can capture energy onboard moving vehicles directly
Computational frameworks	Evaluate the aerodynamics performance of SWEPT
Large Eddy-Simulation (LES)	Horizontal-axis wind turbines simulation under turbulent inflow
Ffowcs Williams-Hawkings (FW-H) framework	Aero-acoustic calculations
Researches on SWEPT components	Generator, battery recharging, diffuser and turbine combination, telescopic structure, dual-rotor wind turbine
Implementation of SWEPT	Electric and hybrid vehicles with SWEPT

IV. THE PREVIOUS METHOD FOR WIND ENERGY MANAGEMENT (NON-IOT)

Efforts to harness Wind energy in Malaysia started in the early 1990s. However, these efforts were not fruitful as they relied heavily on data obtained from local meteorological stations located in low wind speed areas. Malaysia faces even more significant challenges in harnessing wind energy, as it is situated in a low wind speed region. Therefore, researchers concluded that wind data should be obtained over extended periods to account for fluctuations and seasonal effects [43]. Researchers then focused on identifying wind patterns; they used the Mycielski algorithm and K-means clustering methods to predict wind speed.

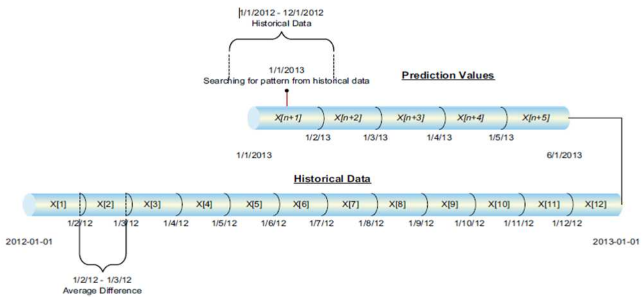

Fig. 3. The flow of the Myscielski algorithm

Results obtained from this method were then compared using a Weibull distribution. Using this method, researchers have successfully predicted the wind speed in Kayseri, Izmir, and Antalya. Figures 3 and 4 below show the Myscielski and K-means clustering method flow. These methods were used to predict wind speed in Kudat (Malaysia), and the results were promising and fairly accurate [44]. Researchers made efforts to simulate wind patterns and turbine performance.

One such effort is the FAST program developed by the National Renewable Energy Lab (NREL). The flow chart in Figure 5 shows the basic flow of the FAST program [45].

In Spain, one of the main European pioneers in the wind energy sector, their wind turbine generators has been operating successfully for over 15 years, well above the average wind turbine lifespan. This is because most of their wind turbines were placed in areas where wind energy is consistent throughout the years, with constant maintenance carried out throughout the year [46]. Figure 6 shows the location of the wind farms installed and developed with an increased annual capacity of power harvested in Spain.

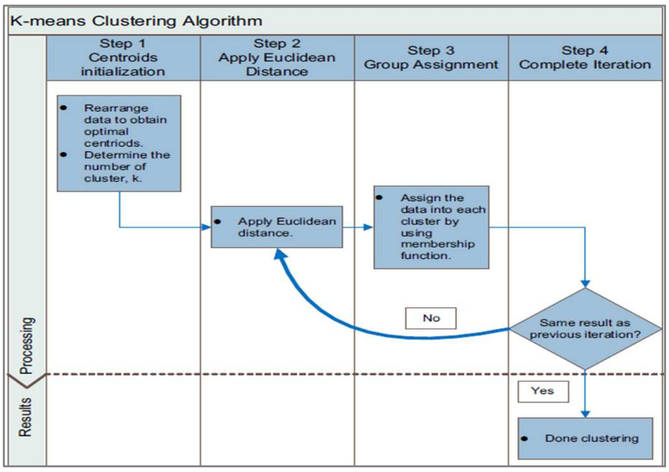

Fig. 4. The basic flow of K-means clustering algorithm

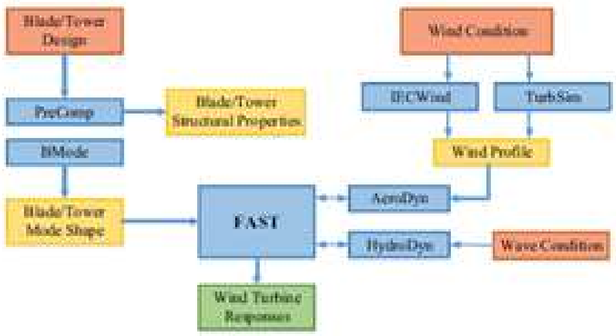

Fig. 5. The basic flow of the FAST program

As for the industry behind wind power, China takes the lead with 48% of the global wind farms. A collection of European nations, namely Germany, Spain, and Denmark, account for 19.7% [47].

Another potential for wind energy is the global offshore locations, where floating farms could be created to generate energy from the strong wind gusts that occur there throughout the year. The only problem is identifying ideal locations for such farms. Researchers implemented the Geographical Information Systems (G.I.S.) method, to estimate potential offshore locations [48].

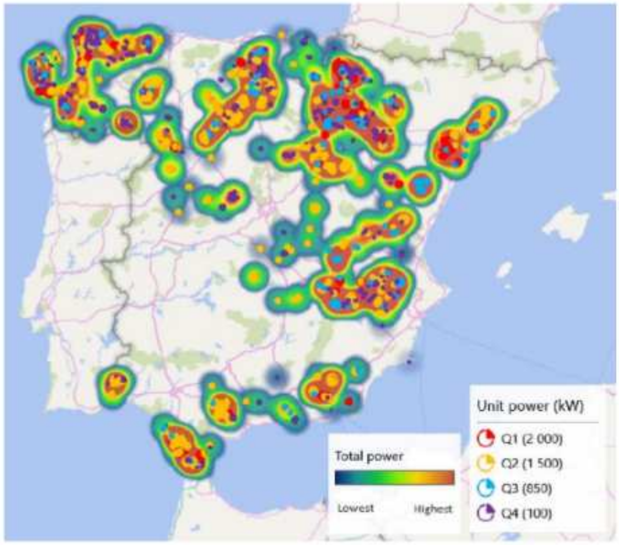

Fig. 6. Geographical distribution of installed WFs in Spain [47]

In Turkey, despite being surrounded by seas on three sides, they haven't found an efficient way to harness the potential of wind energy fully. So, researchers there devised a 3-step process to identify potential locations. The first step is to study the suitability of possible sites with an average wind speed of over 3(m/s). Next, they would use MCSS methods to find the best locations and perform statistical analysis of wind speed using WASP software [49].

In Brazil, despite having a high potential for wind energy, it only contributes 2% of its electricity. So, the Brazilian government set up competitive auctions for the private sector to set up and operate wind farms in the country. They also introduced a few investment coordination mechanisms to reduce financial risks, further attracting the private sector. As a result, wind energy now competes with hydro, biomass, and energy sources in Brazil [50].

The progress of solar and wind technology is a prime example that technology policy can steer the future in a specific direction. However, the potential of the renewable energy transition is not yet fully realized by some key decision-makers and analysts. They need to realize that all parties should continue to contribute to ensuring the change is done successfully for the good of our future [51].

Due to offshore wind farms' rapid growth, the projects must be managed as efficiently as possible. Therefore, researchers proposed the Levelized Cost of Energy (LCOE) approach to evaluate the feasibility of offshore wind farms. This includes both the energy production and the wind farm's lifetime costs [52].

All methods from researchers above are for wind energy management, including wind profile prediction, wind pattern simulation, offshore location estimation, investment coordination, and other evaluation. However, those methods are current general approaches from a few countries with no IoT utilization. The IoT-based methods in wind energy management will be discussed in the next section. The summarized discussion can be found in Table 3.

Table 3 Previous Non-IoT method for Wind Energy Management

Previous Non-IoT methods for Wind Energy Management	
Method	Purpose
Mycielski algorithm and K-means clustering methods	to predict wind speed and patterns
FAST program by the National Renewable Energy Lab (NREL)	Simulate wind patterns and turbine performance
Geographical Information Systems (G.I.S.) method	To estimate potential offshore locations
WASP software	Perform statistical analysis of wind speed
investment coordination mechanisms	Investment management for wind energy
Levelized Cost of Energy (LCOE) approach	Evaluation of lifetime energy production and lifetime costs of the wind farm

V. THE INTERNET OF THINGS (IOT) FOR WIND ENERGY

With the recent development in wireless and networking technologies, such as RFID, W.S.N., R.T.S., cloud computing, and others, the potential for IoT to further empower renewable energy systems is very high. This is especially true as the focus shifts towards miniaturization, portability, and power consumption [53].

To support the Energy industry, including renewables, IoT systems need to support extensive configuration controls often found in an energy farm. To overcome this issue, researchers proposed autoconfiguration platforms. They modified the current "OBSERVE" operation to "ININT", in which a device can identify the detailed attributes and functions of a system autonomously, rather than need to be pre-configured in detail by the operators [54].

Researchers also implemented a low-cost monitoring system using Raspberry Pi; they used sensors for humidity, light, and temperature of the building. Through IoT, the users were able to monitor the collected building data as long as they were connected to the web [55].

A method from other researchers used other components along with the Raspberry Pi, such as (b) Arduino, (c) ZigBee radio transceivers, (d) sensors, and other miscellaneous components. To reduce the cost and complexity of the system, they combined the gateway nodes of the wireless sensor network, database server, and web server in one single-board computer (S.B.C.) hardware platform [56]. In other work, Intelligent Multi-cellular Network Connectivity was introduced to be utilized in IoT applications. This method can handle multiple nodes of applications with a single IoT board. From that, the low-cost monitoring system can be improved in the complexity case [57].

As for IoT services and applications, researchers also organized IoT systems into construction, deployment, termination, execution, and reconfiguration cycles [58]. By setting up these generic life cycles, they could obtain a better understanding of the problems they attempted to solve through the use of IoT devices, systems, and applications [58].

Once data is broadcast to the cloud, issues such as security and storage come to mind. Researchers proposed secured storage protocols that utilize control policies and cryptography concepts for added security. The proposed architecture focuses on the main four components of a cloud-based system, the things (data gathering devices), the gateways, the network infrastructure, and the cloud [59].

Researchers in China aimed to overcome issues limiting their wind energy potential by improving current design methods and counter-measures. Therefore, the Raspberry was utilized to develop Building Monitoring System to monitor the environmental parameters, including temperature, light, humidity, and barometric pressure. This environmental monitoring system can be used in performing data analytics and forecasting for future energy harvesting. Thus, it ensures China remains the leading country in wind energy and is an example to other nations as well [60].

Revisiting the issue of data security and privacy, researchers suggested the application of data provenance, a very active research area in the database and data mining research communities. It focuses on the problem of detecting the origin, the creation, and the propagation processes of data [61]. Researchers conducted comparative analytical studies to vet these platforms to resolve this issue. The studies covered the development, application, device management, system management, data management, and a few other parameters of each platform.

The study found that research-specific platforms are very few and that each platform has its strengths and weaknesses. The full report can be found here [62]. To study the potential of WashCO, LinkCo, and InterfaceCo collaborated and carried out their applications by applying IoT to washing machine systems. It concluded that the prospect of IoT is enormous. However, certain factors such as accessibility, security, and data management are still issues of concern that need to be managed to ensure the success of operations [63].

A few researchers studied on implementation of IoT in renewable energy management. Hybrid MicroGrid with IoT was developed for a hybrid power grid system between homes. The users between the grid systems can export and import their home renewable energy using the web interface [64]. Researchers tested a lightning system supported with IoT and fuzzy logic to improve renewable energy resources efficiency, which is about 24 per cent [65].

An IoT-based energy harvesting system was developed and studied specifically for the renewable energy from water flow. IoT system was used for data monitoring and study. Based on their evaluation of IoT data, the amount of energy harvested from the water flow depends on the source and rate and harvester sensor orientation [66]. A new prototype named Seismic-Volcanic Monitoring Center of the Azores (CIVISA) is proposed for renewable energy monitoring. This energy monitoring prototype was powered with solar energy and controlled by a monitoring device [67].

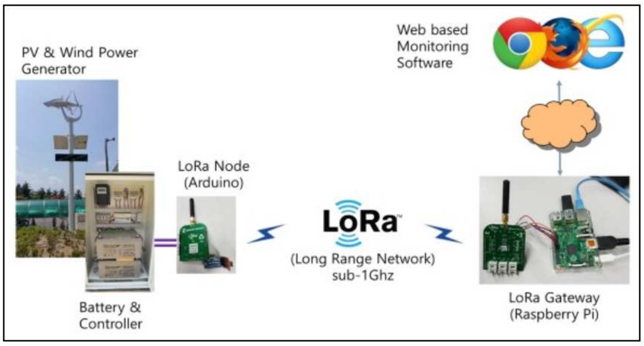

Fig. 7. Renewable energy monitoring system architecture

Other researchers also used LoRa and LoRaWan for IoT platforms. These works are specifically for wind and solar energy harvesting monitoring. The LoRa nodes were attached to wind turbines and other wind generators with sensors, data, and power interface. The architecture of the monitoring system can be found in Figure 7. The systems collected the energy status data from the generator for monitoring and further study and evaluation [68-69].

The IoT approaches have been discussed in this section, where the IoT was used in the general application and also related to energy harvesting, renewable energy management, efficiency study, and data storing security. Some approaches are related to wind energy monitoring, and other approaches are generally related to renewable energy. Those IoT base methods were summarized in Table 4.

Table 4 IoT-based method for wind energy

IoT Implementations in Wind Energy	
Method	Purpose
Auto configuration platforms	Identify the detailed attributes and functions of a system autonomously in energy farms
low-cost monitoring system using Raspberry Pi	Monitor the collected building data
Intelligent Multi-cellular Network Connectivity	Handle multiple nodes of the application
Secured storage protocols	For data cloud security
Building Monitoring System	Monitor the environmental parameters, for data forecasting in future energy harvesting
Hybrid MicroGrid with IoT	Export and import of renewable energy platform
IoT and fuzzy logic-based lightning system	Improve renewable energy resources efficiency
IoT-based energy harvesting system	Energy extraction from the water flow
Seismic-Volcanic Monitoring Center of the Azores (CIVISA)	Renewable energy monitoring
LoRa-based IoT platforms	Wind and solar energy data monitoring

VI. Conclusions

This paper reviews current trends in two research areas that utilize wind power from superhighways and city roads. The first is the Connected Vertical Axis Wind Turbines (C-VAWTs), and the second is the Small-scale Wind energy Portable Turbines (SWEPTs). The paper also reviews recent practices in implementing the Internet of Things (IoT) for general renewable energy and wind energy.

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References

[1] M. Z. Ibrahim, et al. "Wind Characteristics And Gis-Based Spatial Wind Mapping Study In Malaysia", 2014, Journal o Sustainability Science and Management, Vol 9, Number 2, Dec 2014: 1-20.

[2] K. H. Solangi, et al. "Development of solar energy and present policies in Malaysia," 2011 IEEE Conf. on Clean Energy and Technology (CET), KL, 2011, pp. 115-120.

[3] S. Mekhilef and D. Chandrasegaran, "Assessment of offshore wind farms in Malaysia," TENCON 2011 - 2011 IEEE Region 10 Conf., Bali, 2011, pp. 1351-1355.

[4] Belhamadia, M. Mansor and M. A. Younis, "Assessment of wind and solar energy potentials in Malaysia," 2013 IEEE Conf. on Clean Energy and Technology (CEAT), Langkawi, 2013, pp. 152-157.

[5] M. S. Noratiqah, A. Asmat and S. Mansor, "Seasonal wind speed distribution analysis in the west coast of Malaysia," Int. Conf. on Statistics in Science, Business and Engineering (ICSSBE), Langkawi, 2012, pp. 1-5.

[6] M. A. Bhayo, et al. "Analyzing the static and dynamic characteristics of wind energy conversion system using wind turbine simulator," 2017 IEEE Conf. on Energy Conversion (CENCON), KL, 2017, pp. 123-127.

[7] K. Sopian et al., "The theoretical framework of smart energy management Sys. for rural area in Mersing Malaysia," Int. Conf. in Energy and Sustainability in Small Developing Economies (ES2DE), 2017, pp. 1-5.

[8] F. Marquez et al. "Condition monitoring of wind turbines: Techniques and methods" in Renewable Energy, Volume 46, 2012, pages 169-178, ISSN 0960-1481.

[9] "How to select a location for a wind farm," Routledge.com. [Online]. Available: https://www.routledge.com/blog/article/how-to-select-a-location-for-a-wind-farm. [Accessed: 08-Mar-2022].

[10] Gsangaya, K.R., Hajjaj, S., Sultan, M.T.H. et al. (2020) Portable, wireless, and effective internet of things-based sensors for precision agriculture. Int. J. Environ. Sci. Technol. 17, 3901–3916 (2020).

[11] Tick H O, et al. (2018). Energy policy and alternative energy in Malaysia: Issues and challenges for sustainable growth – An update, Renewable and Sustainable Energy Reviews, Volume 81, Part 2, 2018, Pages 3021-3031.

[12] S. Mekhilef et al. (2014). Technical Issues of Grid-Connected Renewable Energy Sources: A New Area of Research. World Renewable Energy Congress, Kingston University, Vol. 3/8, 2014.

[13] A.K. Alsaif (2017). Challenges and Benefits of Integrating Renewable Energy Technologies into the AC Power System Grid. American Journal of Engineering Research, pp. 95-100, 2017.

[14] M. L. Wakulchik (2017). Integrating Renewable Energy with the Grid, Journal of Undergraduate Research, Vol. 9, pp. 1-5, 2017.

[15] A. Al-Aqel, B. K. Lim, E. E. Mohd Noor, T. C. Yap and S. A. Alkaff, "Potentiality of small wind turbines along highway in Malaysia," 2016 Int. Conf. on Robotics, Automation and Sciences (ICORAS), 2016, pp. 1-6, doi:10.1109/ICORAS.2016.7872634.

[16] H F Liew et al. 2020, Review of feasibility wind turbine technologies for highways energy harvesting. J. of Physics: Conference Series. 1432 012059

[17] Khalid M. Saqr, Md. Nor Musa, 2020, A perspective of the Malaysian highway energy consumption and future power supply, Energy Policy, Volume 39, Issue 6, 2011, Pages 3873-3877, ISSN 0301-4215.

[18] S. Bharathi and G. Balaji, (2012). "A Method for Generating Electricity by Fast Moving Vehicles," Appl. Mech. vol. 110–116, pp. 2177–2182.

[19] Mahale, P., Jangid, N., Gite, A. and Patil, T.D. (2015) Vertical Axis Wind Turbine: A Lucid Solution for Global Small Scale Energy Crisis, Journal of Academia and Industrial Research (JAIR), vol. 3, issue 8, pp. 393-396.

[20] Divya1, B., Muthukumari, S., Vaithiynathan, G., Puvaneshwari, G.M., and Mathew, K. (2012) Harnessing Electrical Energy in Highways by Smart Wind Mill, International Journal of Engineering Research and Development, vol. 3, issue 12, pp. 04-09.

[21] Lapointe, C., and Gopalan, H. (2016) Numerical Investigation of Mini Wind Turbines Near Highways, Journal of Solar Energy Engineering, vol. 138, 024503, pp. 1-4.

[22] Kumar, M., and Kumar, K. (2016) Traffic-Driven Energy Generator. Technology Letters, vol. 3, no.1, pp. 10-13.

[23] Behnaz Saboori, Maimunah Sapri, Maizan Bin Baba, "Economic growth, energy consumption and CO2 emission in Organization for Economic Co-operation and Development (OECD) transport sector: A fully modified bi-directional relationship approach," *Energy,* vol 66, pp. 150-161, March 2014

[24] IEA. World energy outlook. Paris: International Energy Agency; 2009.

[25] NOAA National Centers for Environmental Information, State of the Climate: "Global Climate Report for Annual 2015", January 2016.

[26] NOAA National Centers for Environmental Information, State of the Climate: "Global Climate Report for September 2018", October 2018.

[27] Thomas R. Anderson, Ed Hawkins, Philip D Jones, "CO2, The greenhouse effect and global warming: from the pioneering work of Arrhenuis and Callendar to today's Earth System Models," *Endeavour,* vol 40, pp. 178-187, September 2016

[28] Audrey Waits, Anastasia Emelyanova, Antti Oksanen, Khaled Abass, Arja Rautio, "Human infectious diseases and the changing climate in the Artic," *Environment International,* vol. 121, pp. 703-713, December 2018.

[29] Onno Kuik, Frederic Branger, Philippe Quirion, "Competitive advantage in the renewable energy industry: Evidence from a gravity model," *Renewable Energy*, vol 131, pp. 472-481, February 2019

[30] A. Bowen, S.Fankhauser, "The green growth narrative: Paradigm shift or just spin?" *Global Environment Change,* vol 21, pp. 1157-1159, October 2011

[31] REN21, Renewable 2018. Global Status Report,REN21Secretariat, Paris, 2018

[32] Ravi Anant Kishore, Thibaud Coudron, Shashank Priy, "Small-scale wind energy portable turbine (SWEPT)" *Journal of Wind Engineering and Industrial Aerodynamics,* vol 116, pp. 21-31, May 2013

[33] Sanxia Zhang, Kun luo, Renyu Yuan, Qiang Wang, Jianwen Wang, Liru Zhang, Jianren Fan, "Influences of operating parameters on the aerodynamics and aero-acoustics of horizontal-axis wind turbine" *Energy,* vol 160, pp. 597-611, October 2018

[34] Christian Stoeckert, "Wind Turbine Driven Generator to Recharge Batteries In Electric Vehicles", US3876925A, 1974.

[35] Xiaoying Yu, "Portable Wind Power Apparatus for Electric Vehicles", US6897575B1,2005

[36] Richard A. Oman, "Portable Wind Turbine For Charging Batteries", US4324985A, 1980

[37] "Portable Wind Power Generation Device", CN207892765U, 2018

[38] Willis F. Miller "Dual Rotor Wind Turbine", US6945747B1, 2005

[39] Amine El Fathi, Abdelkader Outzourhit, "Technico-economic assessment of lead-acid battery bank for standalone photovoltaic power plant" *Journal of Energy Storage*, vol. 19, pp.185-191, August 2018

[40] B. Faessler, P. Kepplinger, J. Petrasch, "Field testing of repurposed electric vehicle batteries for price-driven grid balancing" *Journal of Energy Storage,* vol. 21, pp. 40-47. October 2018.

[41] Lluc Canals Casals, Mattia Barbero, Cristina Corchero, "Reused second life batteries for aggregated demand response services" *Journal of Cleaner Production,* vol.212, pp. 99-108, December 2018

[42] M. Ghute, et al. (2021). "Power Generation Using Renewable Energy Sources," 2021 Fifth Int. Conf. on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC), 2021, pp. 1722-1724, doi: 10.1109/I-SMAC52330.2021.9640802.

[43] Lip-WahHo, "Wind energy in Malaysia: Past, present and future," Renewable and Sustainable Energy Reviews, p. 17, 2015.

[44] Lee S.W., Kok B.C., Goh K.C., Goh H.H. (2013) Wind Prediction in Malaysia. In: Zelinka I., Vasant P., Barsoum N. (eds) Power, Control and Optimization. Lecture Notes in Electrical Engineering, vol 239. Springer, Heidelberg.

[45] "FAST Revs Up with a v8," Nrel.gov, 25-Feb-2015. [Online]. Available: https://www.nrel.gov/news/program/2015/16473.html. [Accessed: 08-Mar-2022].

[46] Martin, M. D. (2019). Wind energy planning for a sustainable transition to a decarbonized generation scenario based on the opportunity cost of the wind energy: Spanish Iberian Peninsula as case study. Energy Procedia, 1144-1162.

[47] De-Xin, H. (2016). Coping with climate change and China's wind energy sustainable development. Advances in Climate Change Research, 3-9.

[48] Bosch, J. (2018). Temporally explicit and spatially resolved global offshore wind energy. Energy, 766.

[49] Argin, M. (2019). Exploring the offshore wind energy potential of Turkey based on multicriteria. Energy Strategy Reviews, 33-46.

[50] Rego, E. E. (2018). Successful Brazilian experience for promoting wind energy generation. The Electricity Journal, 13-17.

[51] Gielen, D. (2019). The role of renewable energy in the global energy transformation. Energy Strategy Reviews, 38-50.

[52] C.Pillai, A. (2017). Application of an offshore wind farm layout optimization methodology at Middlegrunden wind farm. Ocean Engineering, 287-297.

[53] Gawali, S. K. (2019). Energy Autonomy in IoT Technology. Energy Procedia, 222-226. 15

[54] A. Papageorgiou, M. Zahn, and E. Kovacs, "Efficient auto-configuration of energy-related parameters in cloud-based IoT platforms." 2014 IEEE 3rd International Conference on Cloud Networking (CloudNet), pp. 236-241, 2014, doi: 10.1109/cloudnet.2014.6968998.

[55] Kanga, B. (2017). An experimental study of a reliable IoT gateway. I.C.T. Express, 130-133.

[56] Ferdoush, S. (2014). Wireless Sensor Network System Design using Raspberry Pi and. Procedia Computer Science, 103-110.

[57] Gsangaya, K. R., Hajjaj, S., Hashim, W., & Razali, R. A. (2021). Intelligent Multi-cellular Network Connectivity for Internet of Things Applications. Lecture Notes in Computer Science (LCNS, volume 13051) 310–321.

[58] Rahman, L. F. (2018). Understanding IoT systems: A Life Cycle Approach. Procedia Computer Science, 1057-1062.

[59] Bokefode, J. D. (2016). Developing A Secure Cloud Storage System for Storing IoT. Procedia Computer Science, 43-50.

[60] Perumal, V. S. (2017). Implementation of effective and low-cost building monitoring system (B.M.S.) using raspberry pi. Energy Procedia, 179-185.

[61] Alkhalila, A. (2017). IoT Data Provenance Implementation Challenges. Procedia Computer Science, 1134-1139.

[62] Ray, P. P. (2016). A survey of IoT cloud platforms. Future Computing and Informatics Journal, 35-46.

[63] Saarikko, T. (2017). The Internet of Things: Are you ready for what's coming? Business Horizons, 667-676.

[64] D. K. Aagri and A. Bisht, "Export and Import of Renewable energy by Hybrid MicroGrid via IoT," *Proc. - 2018 3rd Int. Conf. Internet Things Smart Innov. Usages, IoT-SIU 2018*, pp. 18–21, 2018.

[65] S. Nur Altun, M. Dörterler, and I. Alper Doğru, "Fuzzy Logic Based Lighting System Supported with IoT for Renewable Energy Resources," *Proc. - 2018 Innov. Intell. Syst. Appl. Conf. ASYU 2018*, pp. 1–4, 2018.

[66] H. A. Illias, N. S. Ishak, H. Mokhlis, and M. Z. Hossain, "IoT-based hybrid renewable energy harvesting system from water flow," *PECon 2020 - 2020 IEEE Int. Conf. Power Energy*, pp. 204–208, 2020.

[67] A. Garcia and H. Guerra, "Affordable IoT device for renewable energy systems monitoring of the CIVISA's multiparameter remote stations," *2019 Int. Conf. Eng. Appl. ICEA 2019 - Proc.*, 2019.

[68] C. S. Choi, J. D. Jeong, I. W. Lee, and W. K. Park, "LoRa based renewable energy monitoring system with open IoT platform," *Int. Conf. Electron. Inf. Commun. ICEIC 2018*, vol. 2018–January, no. 20172410100040, pp. 1–2, 2018.

[69] K. Mikhaylov, A. Moiz, A. Pouttu, and ..., "LoRa WAN for wind turbine monitoring: Prototype and practical deployment," *... Congr. Ultra ...*, 2018.