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Smart Grids and their Role in Smart Mobility

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Abstract

The transition to electric mobility is an important strategy in the global efforts to reduce greenhouse gas emissions and enhance energy efficiency. This study explores the critical role of integrating electric mobility systems with power grids for sustainable transport and environment. The study analyses key challenges the smart grid capabilities and features like vehicle-to-grid (V2G) interactions in supporting electromobility. findings emphasize the importance of interdisciplinary solutions that align technological innovation with policy measures to build a resilient and sustainable transport-energy nexus. They are revolutionizing the EV industry in many ways like is making EV ownership more affordable and efficient, while at the same time open opportunities for electric vehicles The Smart grid is the direction and trend of power industry development based on the physical grid that combines advanced information & communication technology with operation technology to the traditional grid. Smart grids link power generation, transmission, system transformation, power distribution, electricity consumption and dispatch in two-way participatory manner by coordinating the needs and functions of different participants in the grid environment enabling the system to operate with higher reliability and system stability. Smart grids facilitate the optimization of the electricity mix consisting of both renewable and nonrenewable sources by application of computer programs and hardware to manage power generation, transmission, and distribution resources. The smart grid technology is a product of the fourth industrial revolution (4IR) which is important to achieve fastest technological reformations in electricity generation, transmission, and distribution (T&D) because of growing application of computers, sensors, sensors, and communications. In this study, the use of smart grids in electrification of transport and related products and services including vehicle to gris (V2G), G2G are presented. By plugging abilities and Thing (IoT), Smart grids can optimize energy solutions through flexibility in the management of the diverse energy systems, enhance operational insights, improve maintenance forecasting and self-healing abilities, and create a more secure and safe power system. Smart grids enable power utilities and grid operators to effectively monitor the electricity usage of electric vehicles in real-time, which makes it easier to balance the load on the grid and reduce peak demand and provide an opportunity to optimize the charging of electric vehicles. Smart Grid technology is revolutionizing the electric vehicle industry by making EV ownership more affordable and efficient and opens new opportunities for EV drivers and will thus clearly continue to revolutionize the EV industry in the years to come. The study recommends conversion of the traditional grid to smart grids as a technical solution with significant financial/economic, social, and environmental benefits in the sustainable energy transition. To realize this, it is necessary to build the institutional capacity and put in place policy measures that promote the development of smart grids this like micro grids, modern energy storage, decentralized generation and development of renewable energy resources and technologies.

Keywords
Smart grids; grid optimization; smart grid technology; Internet of Things; smart grid architecture; industry 4.0; sustainable energy; renewable energy; non-renewable energy; energy transition.

1. Introduction

Electromobility is a fundamental pillar of sustainable mobility and climate mitigation strategies globally as electric vehicles (EVs) enable significant reductions in greenhouse gas emissions, with the integration into existing power grid infrastructure presenting new challenges and opportunities in terms of grid stability, and energy access. This study examines the advances in electrification of transport and the key role played by the grid in enabling electromobility(Kabeyi & Olanrewaju, 2025; Kabeyi & Olanrewaju, 2024).

The Shipping, aviation, and road transport jointly account for about 25% of overall emissions and is projected to rise to 30% by 2050. The main challenge for the transport sector is dependency on fossil fuel although it is estimated that 78% of all road transport will be electric by 2050(DNV AS, 2023; Peyvandi et al., 2023).The smart Grid technology is gradually revolutionizing the electric vehicle (EV) industry making EV ownership more affordable and more efficient, while at the same time opening new opportunities for drivers and owners. Smart Grids are digital networks that facilitate two-way communication between electric power providers, consumers, and other grid stakeholders. The smart grid technology has the potential to revolutionize the way electricity is generated, supplied, stored, and used, in a way that is also revolutionizing the way electric vehicles are used and charged(Frąckiewiczi, 2023).

The energy transition requires advanced technologies like smart grids, management systems and renewable energy generation and storage. Managing such a such complex system requires the integration and coordinating several power system components like advanced sensors and smart meters as main data sources in the era of big data, wireless communication, and application of the internet of Things (IoT) (Mostafa et al., 2022; Rathor & Saxena, 2020). This data acquired should be stored, processed, and analyzed to generate the necessary output for efficient deployment and operation of power stations, demand and supply management while integrating renewable energy and clean sources of energy and demand side management options. Very important in a modern power system is energy fuel efficiency, reduction of emissions and waste minimization(Kabeyi & Olanrewaju, 2020; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022e). The benefits from such a modern grid include better asset management, enhanced operations planning, better monitoring and control, reduced cases of voltage instability, accurate prediction, and fault detection in a power system. Such advanced system also faces several challenges in implementation related to aspects like data uncertainty, data security, data quality, and data complexity(Mostafa et al., 2022; Rathor & Saxena, 2020). The smart grid technologies have demonstrated potential to revolutionize the electricity grid by means of two-way communications to improve power system reliability, economy, efficiency, and sustainability in power generation, transmission, and distribution(Moses Jeremiah Barasa Kabeyi & Akanni Oludolapo Olanrewaju, 2022; Kabeyi & Olanrewaju, 2023). smart grids facilitate optimization of the electricity mix of both renewable and non-renewable energy sources for sustainable power generation and supply through existing power system infrastructure.

The electricity grid is undergoing significant changes because of the proliferation of variable renewable energy resources, variable loads like electric car charging, development of intelligent sensors, high-speed signal processors, among other technological developments. Smart grids present the greatest potential advances in the global sustainable energy transition due their ability to significantly improve the grid resilience, reliability, and efficiency (M J B Kabeyi & A O Oludolapo, 2020; Skopik & Smith, 2015). Rapid growth in electricity demand and users and need to sustain variable loads and sources is the main reason for growing interest in smart gris(Agung & Handayani, 2022; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022). Energy transformation and sustainability is a global challenge, today for many facing energy-related issues like wide demand–supply deficiency, over dependency on fossil energy sources, and low access to clean energy. The smart grid technology has ability to address challenges related to smooth transition from traditional to smart energy systems (Bhattarai et al., 2022; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022a, 2022e).

2. The grid

The power grid consists of transmission lines, substations, transformers and other meant to deliver electricity from power plants to end users (Moses Jeremiah Barasa Kabeyi & Akanni Oludolapo Olanrewaju, 2022; US Department of Energy, 2018). The grid usually consists of many power plants of different technologies and characteristics, networks, generators, grid operators and different stakeholders applying different communication levels.

2.1. The Traditional Grid

The coordination in traditional grids, is usually manually controlled(Kabeyi, 2022; Kabeyi & Olanrewaju, 2020). The traditional electric power grid technology is over 100 years old, and its design is meant to feed electricity from large central power plants using high voltage network, covering considerable distances to deliver power to end users via lower voltage distribution network with little flexibility(Moses Jeremiah Barasa Kabeyi & Akanni Oludolapo Olanrewaju, 2022; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022). Over years now, electricity demand has grown rapidly mainly due to social-economic development and industrial growth but the supply mainly comes from cheap traditional sources of energy like coal, gas and petrol that are associated with release of greenhouse gas emissions (GHG) to the atmosphere that are responsible for climate change(Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022a; Ponce-Jara et al., 2017). The electricity grid is being modernized towards advanced consistency, less costs, and greater efficiency through more uptake of renewable energy, advanced control technology and two-way communication. There has been a growing need for substation modernization to cope with fast growth of the grid, growing consumer needs, and technological innovations leading to grid transformation. The Smart grid can help accomplish these technological reformations across the grid in power n generation, transmission and distribution, through more use of sensors, communication and computers(Saumen et al., 2021).

2.2. The Smart Grid

There is a global transformation of the traditional power system that is unidirectional in structure and operation to a configurable and participatory two-way structure where actors or participants can interact with one another (Moses Jeremiah Barasa Kabeyi & Akanni Oludolapo Olanrewaju, 2022; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2021b, 2022e). The main motivation for this transformation is advances in communication, power electronics, and computer technology and increasing need to accommodate the variable renewables and electric cars on the power grid while maintaining. maximum reliability, quality of service, with minimum economic and ecological costs, while maintaining maximum safety for equipment and users and always keeping the voltage and frequency values within the permitted range (Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022f; Moreno Escobar et al., 2021).

The smart grid uses intelligence for integration of user actions connected to the system like consumers, generators, and other stakeholders for delivery of sustainable, economic, and electric power (Moses Jeremiah Barasa Kabeyi & Akanni Oludolapo Olanrewaju, 2022; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022e; Vijayapriya & Kothari, 2011)A smart grid makes use modern communication and computer technology to operate and control the electricity network to better handle potential power system failures(Moses Jeremiah Barasa Kabeyi & Akanni Oludolapo Olanrewaju, 2022; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022; Lund et al., 2017). Therefore, a smart grid is equipped with advanced communication, automation, and information technology systems (IT) that enable real-time bidirectional monitoring and control of electricity and information between sources of power and consumer appliances.

Therefore, a smart grid marks a shift from centralized power generation to decentralized power generation. Smart grids seamlessly integrate the three power system functions of generation, transmission, and distribution are integrated evolving the grid into integrated smarter system. The smart grids facilitate the integration of all forms of power generation and converts a consumer into a producer and consumer (prosumer) enabling households to generate and store electricity both for sell and own use courtesy of the two way power flow and communication facilities(Kiran & Rao, 2018).

2.2.1. Benefits of the smart Grid

The Smart Grid technology presents unprecedented opportunity to transition the energy industry into an era of high availability, reliability, and efficiency. This will enhance economic and environmental health of both developed and developing world economies(Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022c, 2022e; Kabeyi & Olanweraju, 2022). There is need to carry out testing, consumer education, technology improvements, standards development and regulations, and information sharing between energy projects to ensure that the benefits derived from the Smart Grids are realized during the energy transition period(Moses Jeremiah Barasa Kabeyi & Akanni Oludolapo Olanrewaju, 2022; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022d, 2022f). The benefits of smart grid include:

- i.) Smart grids enable more efficient power transmission.
- ii.) They facilitate quicker restoration of electricity in case of power supply disturbances.
- iii.) Smart grids enable reduction in operations, maintenance, and management costs for electricity utilities, which lowers power costs for consumers.
- iv.) Use of smart grids can reduce peak demand which leads to delayed or suspended expansion of capacity leading to reduced or lower electricity rates.

v.) Increased integration of large-scale renewable energy systems
vi.) They facility more efficient and better integration of customer-owner power generation systems, including renewable energy systems thus converting electricity consumers of a traditional grid to prosumers.
vii.) There is improved energy security using smart grids due to increased decentralization of generation which enables increased use of local energy resources, most of which are renewable sources like wind, solar and biomass.
viii.) Facilitate the integration of renewable energy sources in the electricity network.
ix.) Support or facilitate new uses of electricity, like electrification of transport or development of electric vehicles.
x.) Facilitate the emergence of innovative energy efficiency solutions at community level like the development of smart cities or smart neighborhoods(Moses Jeremiah Barasa Kabeyi & Akanni Oludolapo Olanrewaju, 2022; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022; U.S Department of Energy, 2022).

Power supply with the traditional grid is characterized by electricity disruption like blackouts which can have negative impact on almost all industries and services like banking, traffic, communications, water, and security. Worse is power outage in winter, which can leave consumers without heat. With a smart grid, resiliency is added to our electric power system making it better prepared to handle or accommodate emergencies like severe storms, earthquakes, and terrorist attacks(Ourahou et al., 2020; U.S Department of Energy, 2022). The smart grid is managed in a more flexible way to manage constraints like variability and intermittence of energy resources and support of variable loads like electric vehicles(Moses Jeremiah Barasa Kabeyi & Akanni Oludolapo Olanrewaju, 2022). The constraints can change the current system, in which real-time equilibrium is ensured by adapting production to consumption, to one in which adjustment is done more by demand converting the consumer to more important actor in power system control [28]. Therefore smart grids combine a demanding business environment and new technological advances that can transform the energy sector(Ourahou et al., 2020).

2.2.2. Technologies in Smart Grids

Smart grids make use of a broad range of technologies and appliances. They include smart meters, SCADA, and FACTS while several technologies are still in early stages of development like PMU, and V2G technologies. Of the technologies used in smart grids, some are specific to electricity systems, while others cut across other energy systems, but others are common information and communication technology applications in other sectors. The various technologies in smart grids are summarized in Table 1.

Table 1. Technologies in smart grids

	Area of Technology	Hardware	Systems and software	Network deployment
1	Wide area monitoring and control	Phasor measurement units (PMU) and other sensor equipment	Supervisory control and data acquisition (SCADA), wide-area monitoring systems (WAMS), wide area adaptive protection, control, and automation (WAAPCA) and wide-area situational awareness (WASA)	Transmission
2	Information and communication technology integration and office computers	Communication equipment (power line carrier, WiMAX, LTE, RF mesh network, cellular), routers, relays, switches gateway, computers (servers)	Enterprise resource planning software, customer information system	Transmission and distribution
3	renewable, distributed and conventional generation integration	Power conditioning equipment for bulk power and grid support, communication and control	Energy management system (EMS), Distribution management system (DMS), Supervisory control and data	Transmission and distribution

		hardware for generation and enabling storage technology	acquisition system (SCADA), geographic Information system (GIS)	
4	transmission enhancement	Superconductors, Flexible alternating current transmission system (FACTS), High voltage direct current transmission system (HVDC)	Network stability analysis, automatic recovery systems	Transmission
5	Distribution grid management distributed energy resources	Automated re-closers, switches, and capacitors, remote-controlled distributed generation and storage, transformer sensors, wire and cable sensors	GIS, DMS, outage management system (OMS), workforce management system (WMS	Distribution
6	Advanced metering infrastructure (Smart metering)	Smart meter, in-home displays, servers, relays	Meter data management system (MDMS	Distribution and (transmission)
7	Electric transportation charging	Charging infrastructure, batteries, inverters	Energy billing, smart charging grid-to vehicle (G2V) and discharging vehicle to-grid (V2G) methodologies	Distribution
8	Customer-side systems and demand response	Smart appliances, routers, in-home display, building automation systems, thermal accumulators, smart thermostat	Energy dashboards, energy management systems, energy applications for smart phones and tablets	Distribution and (transmission)

From table 1, it is noted that smart grids function because of the various technologies cutting across power, electronics, communication, and computer technology.

The smart grids incorporates technologies that facilitate real time monitoring and control of power making it possible for grid operators to introduce different tariff structures that enable demand side response and management(Kappagantu et al., 2016). Power consumers are also provided with trading or business opportunities created by decentralization of generation through energy savings and revenue by trading over smart grid block chain-driven decentralization and flexibility made possible by digitalization like smart metering and use of flexibility tokens. Consumers can generate for self-consumption when prices are high and sell excess when prices are favorable in a two-way trading over the smart grid. Figure 1 shows diagrammatically the various functions of a smart grid(Moses Jeremiah Barasa Kabeyi & Akanni Oludolapo Olanrewaju, 2022; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022e).

2.2.3. Functions and Application of Smart Grids

From Figure 1, the main functions of smart grids are summarized as integration of renewable energy, smart appliances, distributed generation and related storage, electric car charging infrastructure as well as V2G facilities, transmission, and distribution automation functions, energy efficiency improvement among others.

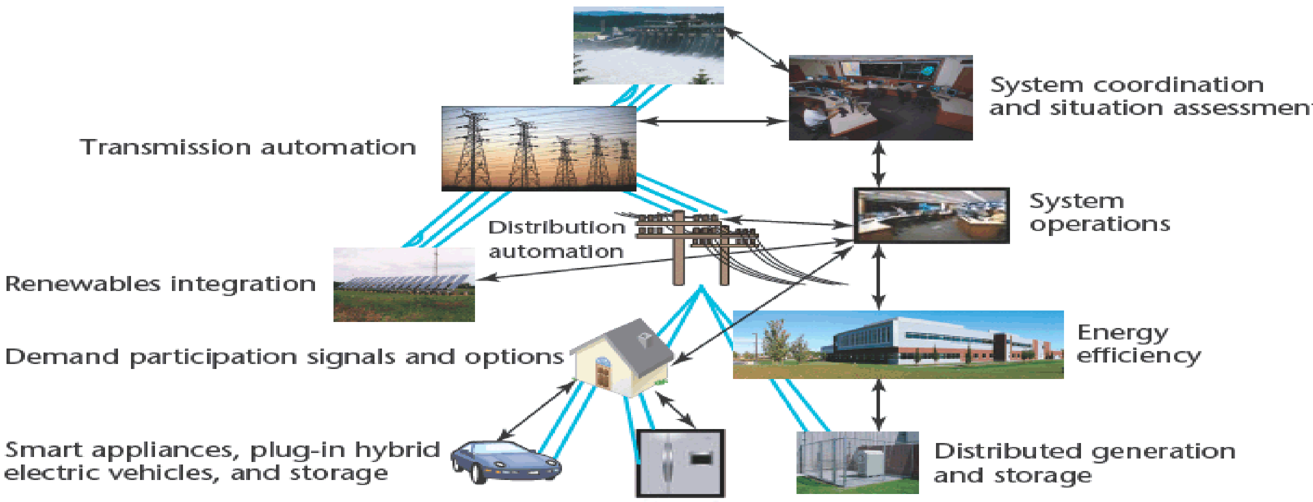

Figure 1. The main functions of the smart grid

Although smart Grids provide better efficiency in monitoring power consumption, manage peak demand by directing power supply to manage peak power needs and enhance efficiency in transmission and distribution, they open an opportunity for information security breaches and other types of security related risks like meter manipulation, high-impact attacks on critical infrastructure that can lead to grid failure(Moses Jeremiah Barasa Kabeyi & Akanni Oludolapo Olanrewaju, 2022).

3. Smart Mobility

Traffic congestion and transport related emissions are serious concerns in cities, in a manner that is not sustainable. Urban transport faces challenges, like air pollution and inefficient use of resources, which hinder economic development that may not be solved by mere road network expansion. Smart connectivity is necessary to integrate the urban infrastructure efficiently. Smart mobility is a cornerstone of a smart city, that can potentially reduce traffic jams, commuting times, and accidents and create opportunities for passengers to customize their movement. The planning of smart mobility solutions is among leading challenges facing large cities globally because it involves a deliberate action backed by advanced technologies. The main segments of smart mobility include intelligent citizen engagement, transport systems, open data, and big data analytics, which are all inter-related as they play a leading role in the successful implementation of smart mobility(Bıyık et al., 2021)

The emergence of the internet and instant information has given opportunities for business owners and customers on both ends of the consumer spectrum away from the manually logging driver data and face-to-face interactions, as well as handshakes deals and first-hand accounts, that formed the basis of truth and the only mode for sharing information and drawing conclusions(Wallin, 2021).To manage swelling populations and growing congestion, innovation needs to be a top priority with big data at the being at the center to ensure smarter decisions and better results. In the modern transport industry, interconnectedness of nearly every aspect of daily work has increased and business owners are searching for technologies and solutions that that enhance capability in on a single, user-friendly platform (Wallin, 2021).

Smart mobility is an intelligent transport and mobility network involving the connection of various elements of technology and mobility, a rethinking of the transportation infrastructure used in daily life and business. It includes the use of traditional motor vehicles, electric vehicles, and public transportation systems, and completely new modes of transportation like on-demand ride sharing services (Uber and Lyft) and carsharing programs. The way people are getting around has changed for reasons like decline in decline in private car ownership, and a rise of completely new mobility. The idea has gotten further traction because of concerns around pollution, traffic congestion, loss of productivity and money (Wallin, 2021). The ecosystem of smart mobility contains a a wide range of alternative modes of transportation, ranging from traditional gas and electric vehicles, rail lines, bike and scooter share programs, autonomous vehicles, and augmented traffic realities where road space is designated for specific types of transport at different points throughout the day(Wallin, 2021).

Smart mobility is the pinnacle of a smart city and is grounded in communication, information, and technological instruments, just like smart grid technologies. Smart mobility involves actions which enhance the user's mobility leading to cost reduction. Smart mobility is therefore not just about integrating technology into urban transport infrastructure, but also calls for participation of the people in a smart and rational way. It generally aids in cutting down emissions and pollution by vehicles and traffic congestion. And aids in raising the transportation quality in an environmentally friendly many which is like the objective of smart grids which also seeks to cut down emissions by increasing decentralized generation and uptake of cleaner locally available sources of energy in a participatory manner by al grid stakeholders through availed technology. (Wallin, 2021).

3.1. Features of Smart Mobility

i.) Smart mobility is a significant element of a smart city plan.
ii.) Smart mobility is the pinnacle of a smart city.
iii.) It is a technique grounded in communication, information, and technological instruments.
iv.) Smart mobility contains several actions that enhance users' mobility by foot, public or private transportation, or any other means of transport.
v.) Smart mobility leads to a reduction in economic costs incurred by the environment and time.
vi.) Smart mobility is not just the embedding of technology into an urban infrastructure,
vii.) It requires citizens to pursue and relate to their urban surroundings in a smart and rational way.
viii.) Smart mobility is generally an approach that aids in the reduction of emissions from vehicles and human congestion.
ix.) Smart mobility helps in improving the quality of transportation in an environmentally friendly manner.

3.2. Benefits of smart mobility systems

Smart mobility has capacity to deliver efficiently several benefits for most businesses in all industries by eliminating redundant systems which cause waste that leads to loss of revenue and valuable time leading to economic benefits to businesses, and the people. It is estimated that congestion within the United States alone is close to USD 160 billion dollars annually whose reduction would result in more accurate scheduling for transportation of goods and timely arrival of goods and people while at the same time led to increased safety due to less f less traffic and better visibility for drivers. By enhancing efficiency with smart mobility services has a positive impact on the economy, businesses and individuals in their private capacity with a a massive decrease in carbon emissions and resulting pollution which will positively improve the quality of life for the urban population. (Wallin, 2021).

3.3. How smart mobility integrates with smart cities

Integration of smart mobility solutions with urban infrastructure and smart grids will significantly improve road safety and efficiently streamline urban economies leading to sustainable business with cost and pollution reductions with reliable access to electricity services. The Vehicle-to-infrastructure (v2i) connectivity using ultrasonic, radar, and camera technologies delivers information in real time to drivers and commuters on networks which helps drivers to avoid dangerous activities before they are visually aware. The resultant fuel economy of vehicles from smooth driving cuts down costs and emissions and time unnecessary delays in traffic congestions. With advances in technologies, the trend towards driverless vehicles and smart cities that can predict and mitigate danger on our behalf becomes a clearer reality making integration with energy and other sectors seamless. (Wallin, 2021).

3.4. Understanding the future of mobility

It is projected that there will be a significant rise in the movement of people and freight and more adoption of smart mobility, with a massive impact on operation of fleet. Close to 90 million commercial vehicles may be connected to telematics systems in a telematics market worth close to USD $20 billion globally. With better vehicle tracking technologies, the result is better consumer satisfaction and a rise in safe driving behavior and intelligent data aggregation by all-in-one platforms. With the rise in smart cities, there will be demand for new roads and restrictions on vehicles that do not meet efficiency and emission standards making it hard for fleets not up-to-date with the latest mobility technologies to compete in an data-driven marketplace Iin a smart environment thus making a positive contribution to the sustainable energy transition(Wallin, 2021).

4. Electrification of Transport Sector

The transport sector is poised for growth and deep transition, in which the fleet size is expected to nearly double between 2023 and 2050, passenger flights are projected to grow by 140% above the pre pandemic level; cargo tone-miles at sea is expected to grow by 40%; and energy demand by the rail is expected to double and passenger numbers are expected to more than double by 2050. The transport sector consumed 121 EJ in 2022, although by 2050, with a much busier world and more goods and people to transport, it is expected that energy demand will reduce by 9%, or 111 EJ because of electrification related efficiencies in road transport. Additionally, a steady switch to zero-emission propulsion biofuels and hydrogen and its derivatives in aviation and maritime will lead to a 44% reduction in total transport-related emissions (DNV AS, 2023).

Electric vehicles introduce both opportunities and challenges for the power systems. Peak energy demand can be significantly increased if many electric vehicles are charged at the same time or uncontrollably causing overloading and power loss. The solution is to employ electric vehicles as dynamic loads used to offer balancing services to the power system. For full realization of the capability of electric vehicles as a flexible or dynamic load, there is need to introduce smart charging procedures which can be executed by the smart grid power system(International Renewable Energy Agency, 2019). The transport industry, particularly cars, is one of the biggest contributors of greenhouse gas emission, hence the need to shift to the use of electric vehicles. Electric vehicles use the chemical energy stored batteries that can be recharged for use in vehicle propulsion and powering other automotive systems(Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022e; M J B Kabeyi & A O Oludolapo, 2020; Kabeyi & Oludolapo, 2021). Although various fuels and technologies are under development for the transport sector, electric vehicles represent one of the most feasible options other than using grid electricity for charging, electric vehicles have potential to act as independent distributed energy sources for the grid(Kiran & Rao, 2018). Electric vehicles offer an efficient opportunity to reduce carbon emissions in the transport sector and hence mitigate climate change. The share of electric vehicles in transport is increasing globally with Europe having over 15% sales share by mid-2021(Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2021; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2021a; Sabine et al., 2021).

Vehicle batteries can be charged by means of the grid by plugging the vehicles to the grid and by means of regenerative braking. Electric vehicles can be classified based on charging typologies. They are battery electric vehicles (BEV), plugin vehicles (PHEV), Hybrid Electric Vehicles (HEV) and Fuel cell Electric Vehicles (FCEV)(Kiran & Rao, 2018). The main motivation for electrification of transport sector is that it accounts for about 30% of world energy consumption and 72% of global oil demand making electric vehicles a key avenue for greenhouse gas emissions control and the attainment of the global climate targets (Kiran & Rao, 2018). The main challenges facing electric vehicles include grid infrastructure, the communication, and control(Lopes et al., 2011; Majeed Butt et al., 2021). Electric vehicles promise to play a key role globally in the energy transition because of growing concern on fossil fuel depletion and related emissions. Since vehicle battery energy is not fully used each day, they have a potential to provide peak shaving service (Uddin et al., 2018). Smart charging can be centrally done through aggregators or can be decentralized using decentralized control structures. Aggregators are used to achieve optimal scheduling of each electric vehicle (EV). In decentralized charging systems, electric vehicles choose their own charging methods without contacting the central controller or other linked electric vehicles. Smart charging using both centralized and decentralized systems can effectively reduce energy costs and prevent the overloading of grid components by shifting peak demand(Bhattarai et al., 2022)

The main challenges facing electrification of transport and application in peak shaving are.

- i.) The electric vehicles can only deliver power to the grid when the vehicle is packed, and they are currently not widely deployed.
- ii.) It is not practical for a single vehicle to meet peak load demand alone hence many vehicles and infrastructure must be deployed and controlled together by a third party.
- iii.) It is a technical challenge to synchronise the charging and discharging of a multitude of electric vehicles simultaneously.
- iv.) Lack of critical infrastructure for grid integration of electric vehicles especially in highly urbanised regions(Uddin et al., 2018).
- v.) Charging can cause direct stress to the grid as it is often done at home, commercial and public ideally designed for other applications(Lopes et al., 2011; Majeed Butt et al., 2021).

However, when parked and plugged into power grid, electric vehicles absorb energy and store it in batteries. By provision of two-way power flow capability, these vehicles can also supply power back to the electricity grid in a concept popularly known as V2G (Vehicle to Grid) concept(Lopes et al., 2011).

Since smart grids are equipped with advanced technologies for communication, metering and control, they offer electric vehicles the ability to charge and act as a flexible energy source for the grid(Young, 2017). Therefore if well planned and with adherence to standards set, electric vehicles charging can improve power quality and the performance (Lopes et al., 2011; Young, 2017). An important feature or capability of smart grids is accommodation of support of electric vehicle services making them an important tool in the energy transition(M J B Kabeyi & A O Oludolapo, 2020). Electrification of transportation is becoming a reality with advances in battery storage technology and the development of smart grids. The main motivation is that the transport sector accounts for about 30% of world energy consumption and 72% of global oil demand making electric vehicles a key avenue for greenhouse gas emissions control and the attainment of the global climate targets (M. Kabeyi & O. Olanrewaju, 2022; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022b; Moses Jeremiah B Kabeyi & Akanni O Oludolapo, 2020; Kiran & Rao, 2018).

Electric vehicles have continued to increase globally with 10 million electric cars by the end of the year 2020. Registration of electric cars increased by 41% in 2020, even in the face of the global pandemic-related global economic downturn and reduction in car sales by 16%(International Energy Agency, 2021). About 3 million electric accounting for a 4.6% share of global sales were realized with Europe overtaking China as the world's largest market for electric vehicle (EV). Electric bus and truck increased in numbers globally to reach 600 000 and 31 000 respectively(International Energy Agency, 2021; Taliotis et al., 2020). The global share of electric vehicles is increasing with sales rising to 15% of sales in Europe mid 2021 mainly consisting of plug-in hybrid electric vehicles (PHEV) and the battery electric vehicles (BEV) (Sabine et al., 2021).

Electrification of transportation is becoming a reality with advances in battery storage technology and the development of smart grids. Therefore, a key requirement for successful energy transition via the electrification of transportation sector is the development of the smart grid. The exact amount of actual number of emissions reductions due to electrification of transport vehicles dependent on when and where drivers charge the vehicles and composition of electricity mix(Moses Jeremiah Barasa Kabeyi & Akanni Oludolapo Olanrewaju, 2022; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022e; Kiran & Rao, 2018).

4.1. How Smart Grids are Revolutionizing

The electric vehicle (EV) industry is experiencing a major revolution with the introduction of Smart Grid technology. Smart Grids are digital networks that allow two-way communication between electricity providers and consumers. This technology has the potential to revolutionize the way electricity is supplied, stored and used, and it is revolutionizing the way EVs are used and charged(Frąckiewiczi, 2023). Smart Grid technology allows electric vehicle owners s to charge vehicles more efficiently and can be used to set up automated charging schedules, to ensure charging is done can charge when electricity prices are lowest often during off peak which leads to significant cost saving while at the same time avoiding grid overload..(Frąckiewiczi, 2023). They help vehicles to easily connect renewable energy sources like solar or wind power which reduces their bills and emissions. They can access charging stations. Smart Grids can allow EV owners to easily locate the charging stations and make payments quickly and securely hence lower downtown.

The smart grids also help electric vehicle owners to access charging stations in remote areas where access to electricity is limited by establishing microgrids that enhance decentralized generation thus opening up new opportunities for EV drivers and make electric vehicles more viable in rural areas. Therefore, Smart Grid technology is revolutionizing the electric vehicle industry by making EV ownership more affordable and efficient, and opens new opportunities for EV drivers and will thus clearly continue to revolutionize the EV industry in the years to come(Frąckiewiczi, 2023).

4.2. Exploring the Future of Electric Vehicle Transportation and Smart Grids

The future of electric vehicle transportation and smart grids is most likely to have a growing impact in many countries. The increase in green energy and vehicle electrification is expected to be the primary form of transport in many countries, hence smart grids will play a crucial role in managing electricity demands and revolutionize energy consumption(Frąckiewiczi, 2023).Electrification of transport needs a reliable and efficient power supply, making smart grids important. The use of smart grids will allow consumers to charge their vehicles at home or work, which reduces the need to charge in public places making it more convenient. The future of electric vehicle transportation and smart grids is an exciting one, and the possibilities are endless. With (Frąckiewiczi, 2023).

4.3. Benefits of Smart Grids for EV Charging Infrastructure

Smart grids provide potential benefits to electric vehicle (EV) charging infrastructure by applying their advanced digital technologies to monitor, sense, and manage the delivery of electricity for the purpose of charging electric cars. The main benefits of smart grids for EV charging infrastructure are improved reliability as they can detect and respond to outages in real-time, allowing for a more reliable charging experience. Smart grids can remotely monitor and maintain charging infrastructure, thus reducing the need for costly in-person repairs and can also help reduce the cost of charging infrastructure. They also enable dynamic pricing of electricity, which helps to reduce the cost of charging during times of peak demand and shift demand to off peak hours with benefits to the grid and consumers. Smart grids also help integrate renewable energy sources of energy which provides both environmental and economic benefits. Above all, smart grids aid in improving electric vehicle efficiency charging infrastructure. Efficiency by providing real-time data regarding the power grid, to support more efficient routing of electricity to EV charging systems and they help to optimize the charging process, providing a more efficient way of managing the charging process (Frąckiewiczi, 2023).

4.4. The Impact of Smart Grids on Reducing Emissions from Electric Vehicles

Smart grids have huge potential to reduce greenhouse gas emissions from electric vehicles (EVs) in several by enabling efficient management of energy demand and supply and maximizing the impact of renewable energy sources in the transport sector using electric vehicles since the smart grids enable renewable energy sources to be used more efficiently and in a more cost-effective manner with maximum uptake by the grid(Kabeyi & Olanrewaju, 2020; Moses Jeremiah Barasa Kabeyi & Akanni Oludolapo Olanrewaju, 2022; Kabeyi & Olanrewaju, 2023).

Smart grids also provide a platform for more efficient charging of the car batteries since smart grids connected EV chargers can be programmed to charge during off-peak or when uptake of renewables is maximum, thereby reducing the amount of energy used and consequently reducing emissions.

The smart grids also help by providing capacity to detect and respond to fluctuations in the power grid in real-time basis. Therefore, electric vehicles can be charged or discharged that reduces or minimizes their impact on the grid. e.g., in the case of unexpectedly large surge in demand for electricity, the electric vehicles that are parked can be programmed to draw less power from the grid, which helps stabilize the grids.

Additionally, the smart grids also provide a platform that promotes the use of electric vehicles EVs by enabling dynamic pricing models which can incentivize the use of EVs to buy power at a discounted rate when prices are low. With vehicle to rid (V2G) and grid to vehicle (G2G) infrastructure, the parked cars can also supply power back to the grid during the peak when prices are high hence earn revenue or savings to car owners and help stabilize the grid and economically use excess electricity for charging. This encourage power consumers to adopt electric vehicles this thereby reducing emissions from traditional cars(Kabeyi & Olanrewaju, 2023).

Overall, the smart grids have a key role in reducing emissions from the transport sector by supplying a platform for more efficient energy management, better charging capabilities, and better control of energy demand and supply. By putting in place the right policies smart grids can help make electric vehicles to be a more viable and sustainable option for transport and reduce the greenhouse gas emissions from the vehicles (Frąckiewiczi, 2023).

4.5. Challenges and Opportunities of Smart Grids for EV Transportation

The widespread adoption of electric vehicles (EVs) is necessary to transition to a more sustainable energy system but presents significant challenges for utilities and grid operators. Smart grids which are still under development can address several challenges and introduce new opportunities for electrification of transport like optimization of charging taking advantage of differential pricing of power to schedule charging and guarantee grid stability. Smart grids can also support or facilitate peer-to-peer energy trading, thus allowing EV owners to purchase excess energy from other EV owners at a discounted rate.

The challenges of Smart grids include extensive investment requirements in infrastructure and technology, and a risk that customers may be reluctant to adopt the technology over concerns on privacy and security of data and systems since smart grids are vulnerable to cyber-attacks.

Overall though, the smart grids promise to revolutionize electric vehicle transport and reduce the environmental impact of the transportation sector and so operators and utility owners should overcome these challenges of to realize their full potential of smart grids and electric transportation(Frąckiewiczi, 2023).

5. V2X Technologies

Electric vehicles apply an electric drive traction system consisting of one or more devices for storage of electrical energy or electrical energy conditioning devices or one or more electrical machines meant to transform electrical energy often in stored form to mechanical energy which is transmitted to vehicle wheels to drive the vehicle. This is an all-electric vehicle, or a pure electric vehicle (BEV, for Battery Electric Vehicle). Storage often require regular recharging by connecting the vehicle to an electricity grid or by standard exchange of battery(Ouaissa et al., 2021). Electric vehicles are designed to limit the use of Internal Combustion Engine Vehicles (ICEV) and limit dependency on oil as an energy source. Energy for electric cars is stored in fuel Cells (FCs), and or Ultra-Capacitors (UCs) as opposed to fossil fuel which is stored in a fuel tank. The main components of an electric vehicle system are the motor, controller, charger, power supply, and drive train. Electric vehicles available include the lower-end electric vehicles like Nissan Leaf and higher-end electric vehicles like the Tesla Model S. The EV are cleaner, can be used in peak load shaving, reduce grid infrastructure requirements, act as mobile distributed generation or electric power, etc. but their disadvantages include limited range, need new infrastructure for development, have long charging time; and are associated with adverse battery effects(Ouaissa et al., 2021; Parazdeh et al., 2022).

There are several challenges associated with charging electric vehicles via the smart grid. These challenges include overloading, imbalance, under-voltage, etc. These issues are with EV charging are managed via control called Vehicle-to-Grid (V2G) technology. The technology enables electric vehicles to charge and supply electricity and services to the grid, via an aggregator, for compensation(Ouaissa et al., 2021). There are several V2G technology subsets like Vehicle-To-House (V2H) where the vehicle is in the owner's residence, Vehicle-To-Building (V2B) in which the vehicle is in a commercial building. In these arrangements, the battery power supplements the electrical charge of the local buildings without transferring power to the grid in the event of power failure in the grid(Ouaissa et al., 2021)

The V2X technologies are associated with grid connected vehicles like the Vehicle to Grid (V2G), vehicle to house (V2H), and vehicle to vehicle (V2V), where V2G refers connecting of an electric vehicle to the electricity grid for battery charging and discharge. The vehicles are referred to as grid connected EVs (GEVs) (Bhattarai et al., 2022; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022). The EV represents a significant and radical change in the transport sector engine driven vehicles and in the production of EV. The reason is that an electric vehicle is powered by electricity which can be generated from many sources like hydropower, wind, nuclear, wind, photovoltaic etc. An electric vehicle needs more energy compared the electrical needs of houses for heating and lighting. On the other hand, electric vehicles can be considered as electricity storage systems for the grid. Electric vehicles store electricity that can be used during peak periods to stabilize the grid. The main objective is to meet energy needs of customers under the constraint of not destabilizing the grid (Ouaissa et al., 2021)

As the interest in alternative sources of energy and technologies increases, there is potential for massive penetration of electricity into the grid and widespread use of DER (distributed energy sources) is expected soon. For load management and resource scheduling, a collection unit, VPP (virtual power plant) may be applied. The vehicle-to-grid (V2G) technology enables fixed or parked voltage batteries to serve as distributed sources, for storage and release of energy at appropriate times, in as bidirectional power exchange between the AC mains and DC EV batteries. The bidirectional exchange of power is realized by use of bidirectional electronic power converters connecting the grid and electric vehicle (EV) batteries. Most bidirectional converters for V2G applications use of two dedicated power conversion phases – an AC–DC two-phase conversion step that assist in modifying the power factor, followed by a bidirectional DC–DC conversion phase, to provide voltage matching.(Parazdeh et al., 2022). The bidirectional electronic converters, used i.e. AC–DC (BADC) and DC–DC (BDC), facilitate G2V and V2G electricity transmission between electric vehicles and the grid. Bidirectional converters facilitate high efficiency energy conversion and in the e transition from the conventional to electric vehicles, enable realization of a greener environment(Ouaissa et al., 2021).

The V2G is a promising technology that enables idle or parked electric vehicles to act power plants for grid power supply, with ability to store electricity and release at appropriate times, to facilitate power exchange between grid and the electric car/vehicle. This approach increases generation capacity and improves power system stability, efficiency and reliability of the grid(Parazdeh et al., 2022). The development of smart grids and growth of electric vehicles has generated momentum for growth of vehicle-to-grid (V2G) technology. With V2G, one can use his vehicle to power his home, charge phones, power lights and even operate the fridge during time of high electricity price or during a grid outage and supply excess power to the grid when prices are favorable. The vehicle-to-grid technology (V2G) , which is also known as vehicle-grid integration (VGI), creates an extra power source when weather dependent renewable energy sources are not available. A home can use solar power to generate electricity during the day but use the electric vehicle to supply a secondary source of power if needed e.g. at night and sell excess to the grid(Parazdeh et al., 2022).

Peak demand generally occurs between 5 p.m. and 11 p.m. for most grids globally. This is the time when most private and public vehicles are parked at homes or parking stations. At this period, the vehicle to house (V2H) technology will enable the parked vehicles to supply electricity to home to meet demand peak demand while any excess can be exported to the grid. The electricity prices are generally lower during off-peak hours. This is therefore used to charge the vehicle can be for peak time use. The car can also be charged using solar energy like rooftop solar PV. The V2G technology can be applied by having electric vehicles clustered via an aggregator to offer grid power services like voltage regulation, load leveling, and peak shaving, at a lower cost and with less environmental impact which makes the smart grid technology ideal for deployment of V2G and hence play an important role in the energy transition(Bhattarai et al., 2022; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022e, 2022f).

The communication between the grid and electric vehicles facilitates sharing and exchange of information with respect to the state of charge of electric vehicles, availability of recharging stations and user data. Electric vehicles are in most of the time in a state of rest in the garages of the houses or in the parking lots, hence they can be easily charged by the G2V system and be later used as a source of charge for the grid. The communication between electric vehicles and smart grid takes place in V2G discharge mode, from the vehicle to the grid, with the vehicle as source of distributed generation and G2V which is charging mode. Drivers benefit from the use of electric vehicles since electricity is cheaper than petroleum power. The electric vehicles also provide income to vehicle owners by selling power to the grid (Ouaissa et al., 2021).

6. Smart Cities and streetlight automation

Smart devices are key to efficient energy management and optimization while the intelligent application of smart grid is a key requirement for the establishment of smart cities. Smart cities have been identified as the ultimate solution to complex challenges facing urban centers. Cities are important entities because it is estimated that by the year 2050, about 70% of the world population will be living in urban centers or cities(Farmanbar et al., 2019). There is growing interest in linking in linking interfacing items via networks. The objective of smartening devices is to enable sharing of information or access with other devices to facilitate smart decisions with available internet and communication infrastructures. Smartness of a city refers to the desire of improve the quality of life in a city and living standards of the city residents in terms of information use and communications technology (ICT) capabilities and applications, although use of ICT per se does not constitute a smart city (Farmanbar et al., 2019). The main challenges facing urbanization which should be resolved are shortage of resources, energy management, waste management, obsolete or aging of existing infrastructures, environmental and human health problems among others (Farmanbar et al., 2019) .

Smart grid technologies are playing an important role in urban low-carbon transitions. As they are seen as clean innovations and indispensable strategy to realize the mass integration of renewable energies in cities(Quitzow & Rohde, 2021). Smart grid solutions have become useful in the development of smart cities. As the Growing populations has created jam-packed cities. As technology continues to advance, the concept of a smart city is quite appealing. To realize the dream of a smart city, require advanced power networks that can handle the plethora of information transmission requirements(Partida, 2021). A smart city can be defined as a city that takes advantage of computers, information, and communication technology to generate interactive and responsive infrastructural systems and public services. The goal of a smart city is to use critical data and information to ensure efficient delivery of utilities, like water, public road transport, power supply, and other consumer services. .Therefore smart electricity solutions form the basis of smart city development and transformation (Partida, 2021; Quitzow & Rohde, 2021). According to (Farmanbar et al., 2019). The smart city concept elevates the intelligence of the city by connecting the physical environment, social, business, and ICT infrastructure for of the city and balances the demand and supply of different functionalities(Farmanbar et al., 2019; Ma et al., 2021).

Smart cities like Berlin are increasingly relying on high-tech innovation to deal with urban problems like transport congestion, people's participation in governance, and environmental management. City administrations are putting in place measures and strategies like opening urban laboratories, creating innovation spaces and other sites for technological experimentation to attract ICT companies and compete in the race for digital modernization and progress. Smart urbanization is rapidly being developed in many countries and major cities globally in both developed and developing countries(Partida, 2021; Quitzow & Rohde, 2021).

Cities around the world spend significant energy resources on street lighting and traffic control. Use of smart grids can enhance efficiency, reliability and hence reduce the energy consumption on street lighting. This can be achieved by seamless connection to different suppliers' sources, use of on/off timing control facilities equipped with the ability to synchronize with an astronomical clock. Others are the use of voltage dimming facility that responds to time-setting and traffic condition. Additionally, each lamp can be facilitated with elements for power factor improvement as well as individual lamp control. This combination leads to significant saving in energy costs. Installation of street light automation (SLA) systems can lead to energy savings by as much as 50% based on experience from similar programs(Kappagantu et al., 2016).

Smart power grids are adding value to the concept of smart cities by enabling the following services and products to urban dwellers.

- i.) Efficient power transmission and distribution within cities
- ii.) Better security measures and infrastructure like affordable street lighting
- iii.) Faster restoration of electricity whenever disruptions are experienced.
- iv.) Efficient and cost-effective service delivery through cost reduction and wastage minimisation
- v.) Reduced electricity tariffs and lower energy costs
- vi.) High integration of urban renewable energy sources like solar power from rooftops

The concept of smart cities is realised by use digital technologies like the Internet of Things (IoT), artificial intelligence (AI), automation, and 5G, that facilitate a two-way communication between various utilities in a smart city and the dwellers. These technologies are already in use by industries, like health care. The development of smart cities relies on key power key electricity grid technologies like electric cars, distributed energy or electricity storage, smart meters, smart appliances, smart buildings, and decentralised generation. With global smart grid technology market expected to reach $55.9 billion by 2026, it is evident that smart grid technology has an important socioeconomic and technical role to place in the smart cities development (Farmanbar et al., 2019; Partida, 2021).

7. Challenges Of Smart Grids

Smart grids apply modern cutting-edge technology to address multiple challenges of the traditional grid while at the same time providing opportunities to improve their efficiency and reliability. However, several technical and socioeconomic challenges limit the development and application of the smart grid(Bhattarai et al., 2022; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022). Smart grids employ power electronics technologies like FACTS and RACDS, efficient energy storage systems, etc. which have high initial cost requirements.

Technical challenges in the operation of smart grids include database management and cyber security. Lack of consumer understanding on operation and opportunities of smart grid technology is lack of consumer understanding about the smart grid, hence the need to educate the public on the concept of a smart grid, applications, opportunities, and its role in the energy transition. For consumers to effectively participate in demand response and other services requires training (Bhattarai et al., 2022; M. Kabeyi & O. Olanrewaju, 2022; Moses Jeremiah Barasa Kabeyi & Akanni Oludolapo Olanrewaju, 2022). The challenges facing development and application of smart grids are summarized in Figure 1.

Figure 2. Challenges of smart grid development and use

Figure 2 shows the various challenges facing smart grid development. The challenges are inadequate grid infrastructure, lack of knowledge and skills by industry workforce, limited capacity of energy storage systems, database management to secure user confidentiality and privacy, cyber security challenges like viruses and cyber-attacks, high initial capital; investments, lack of supporting policy and legal framework, and lack of consumer awareness hence ignorance of immense opportunities offered by smart grids.

Smart grid development is both a social and technological endeavor. The introduction of smart grids has profound effect on rules, regulations, norms, socially and culturally guided patterns of thinking and operation of power systems since they are highly institutionalized. Smart grids development require the development of new standards and regulations, new policies, and new market mechanisms while at the same time new technologies must be natured and allowed to mature with minor disruptions(Rohde & Hielscher, 2021). Stakeholders like technology manufacturers and information and communication technology developers, must develop use friendly and effective novel technologies and business models in power system operations and maintenance(Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022; M J B Kabeyi & A O Oludolapo, 2020; Lund et al., 2017).

There are several challenges affecting smart grid development and deployment. There is need for greater awareness among policy makers and stakeholders on the various capabilities and benefits of smart grids to facilitate energy-efficiency and renewable resources in power systems [66]. Rapid changes in information and communications technologies and how they are being deployed in other areas of an economy like manufacturing, finance, healthcare offer new solutions for faster deployment of smart grid technology [66]. Developing countries are most affected by the challenges of smart grid development as they are still grappling with other important developmental and technical issues like extreme poverty, limited access to capital, political instability, government bureaucracies, high level of power theft and other system losses which may have precedence and hindrance to investment in grid smartening (Nasir et al., 2021; Ponce-Jara et al., 2017).The main technical and socio challenges or limitations of smart grids include interoperability issues, cyber and physical security, high costs, confidentiality, and privacy challenges among others.

4.1. Cost challenges

The biggest impediment to the development and implementation of smart grids is cost. The main cost elements in smart grid development are associated with the power transmission and distribution system, electricity metering, and critical technologies. In economic analysis and financial feasibility, a country's capacity to pay for the development cost for smart grid infrastructure is paramount which ultimately disadvantages the developing countries in implementing smart grid infrastructure(Majeed Butt et al., 2021; Young, 2017). Smartening of the traditional grid requires the integration of additional sensors to the infrastructure which is an expensive investment undertaken by distribution grid operators(International Energy Agency, 2011; Skopik & Smith, 2015).

4.2. Cyber Security

There are increased possibilities of remote operation of smart grid power systems because the grids are large-scale system with participants widely spread between power plants and electricity consumers and devices which also creates demand for protection of resources against theft, abuse, and malicious activities (Bari et al., 2014).The Electric Power Research Institute has identified power system cyber security as one of the greatest issues facing smart grid. It is necessary to identify weaknesses of the smart grids exploited by attackers by use of Smart Grid Systems Treats Analysis and by integration of Systems Security Threat Models. There are various approaches used to address cyber-physical security issue for Wide-Area Monitoring and protection and control which are vulnerable to a coordinated cyber-attack. Overall, it is necessary to assess the Smart Grid security by review of its methodology to identify weaknesses(Majeed Butt et al., 2021). Since smart grids are deployed across the value chain, there is increase in points of interconnection with other information networks which exposes the system to potential threat of cyber-attack to important power management systems and infrastructure(international Energy Agency, 2015).

The smart grid is heavily dependent on ICT which ultimately increases the complexity and the number channels for possible cyber-attacks. The cyber-attacks may target the distribution infrastructure not necessarily to cause power blackouts but other destructive disruptive activities like energy meter manipulation, blackmail, power supply disruptions, damage of equipment, damage of distribution or customer equipment (International Energy Agency, 2011; Skopik & Smith, 2015)

Therefore, it is necessary to ensure that cyber security is an essential aspect of any smart grid design and operations(UNECE, 2016). Interoperability and cyber security can be achieved only through rigorous implementation of various standards.

4.3. Interoperability

The communication infrastructure for smart grid should meet specifications in terms of time synchronization, data delivery efficiency, latency reliability, and multicast support. Additionally, the main challenge in networking communications in smart grid is interoperability(Bari et al., 2014). Rigorous implementation of applicable standards is an effective measure to achieve interoperability. The National Institute of Standards and Technology (NIST) has put in place interoperability standards in areas like advanced metering infrastructure (AMI), end to end security, metering, communication between control centers, substation automation and protection, energy management system interfaces, power system control operations information security, phasor measurement unit (PMU) communications, electrical and physical interconnections between utility and distributed generation (DG), security for intelligent electronic devices (IEDs), cyber security standards and guidelines for federal information systems and bulk power systems, home area network (HAN) device communication, measurement, and information model and smart grid Interoperability Panel (SGIP) catalogue of standards.

It is advisable for each country to develop their own standards for smooth implementation of smart grid considering their existing standards and for easy implementation. However, internationally accepted standards and security should also be put in by all countries involved in the smart grid implementation to make the power grid a homogeneous global grid(Vineetha & Babu, 2014).

4.4. Confidentiality challenges

Access Control and Identity Management is needed for confidentiality of data transmitted via smart grids. There is need for authentication to verify identity of the receivers of and avoid any disruption or exploitation. Only authenticated users should be allowed access to the control center for transmission, and distribution grids(Umar et al., 2016).

4.5. Privacy and Security Policies

With wide scale interconnectivity and system access including the growth of Internet of Things associated with smart grid development, privacy, and development of far policies for all stakeholders is a real challenge as objectives and needs may differ and even conflict among stakeholders(Umar et al., 2016). Therefore, there is a huge necessity for suitable security policies to establish relationships between the consumers, utilities, generating companies, transmission firms, and third parties, although applying security and privacy policies in a manner that does not lead to dissatisfaction which is a complex affair(Umar et al., 2016).

4.6. Defence Against Threats
The smart grids have inherent vulnerabilities against which it must be protected. This can be achieved by building an effective, layered defence system for protection of the smart grid infrastructure(Umar et al., 2016). This defence or protection against the threats or vulnerabilities give the network segmentation and access control to defend against denial-of-service (DoS). Technologies used include firewall, virtual private network (VPN), intrusion prevention system (IPS) [66]. This leads to extra investment in technology and resources adding to system costs(Kumaran et al., 2013).

4.7. Physical Security
Smart grid systems have thousands or millions of widely spread remote points and networks. This the challenge of policing or physical protection from theft, sabotage and illegal or unauthorised access(Umar et al., 2016). Therefore, physical protection is a real challenge for smart grids. Additionally, the wider geographical dispersion of the many assets and systems makes it difficult to access all of the terminals for both maintenance and protection(Asia Pacific Economic Cooperation, 2011; Kumaran et al., 2013)

4.8. Connectivity challenges
This refers to the communications connectivity and interchange within the smart grid infrastructure and between users or stakeholders(Umar et al., 2016). The current trend in communication technology also implies a transition from analogue to digital communication and towards an Internet like distributed environment where large number of devices are interconnected. Not all regions, devices or users have access to modern and effective internet and communication infrastructure especially where the services a publicly accesses and not limited to the grid system(Kumaran et al., 2013; Umar et al., 2016).

5. Results and Discussion
The research highlights the urgent need for a cohesive and forward-thinking approach to electric mobility integration. Important developments and innovations impacting electromobility include charging optimization, renewable energy integration, V2G applications, and governance strategies(Kabeyi & Olanrewaju 2022; M J B Kabeyi & A O Olanrewaju, 2022). Several challenges remain in electromobility but these study offers several actionable insights that can guide policymakers, urban planners, and industry leaders toward an efficient, resilient, and equitable transport-energy ecosystem. Enhanced interdisciplinary collaboration, data-driven infrastructure planning, and progressive regulatory frameworks, will accelerate the shift toward a fully electrified transport future. Sustainable Mobility and Transport requires strategic integration of mobility systems with power grid infrastructures(Kabeyi, 2024; Kabeyi & Olanrewaju, 2023).

The Smart Grid system is a complex and multi-disciplinary, and relatively under-researched concept. Smart grids implement smart contracts which are integrated with smart energy meters hence allowing tracking of energy profiles against available energy flexibility transactions as well as decentralized settlement of participant wallets(Antal et al., 2021). The study demonstrated the significance of block chain and smart contract technology which is growing rapidly with many companies and industries adopting the technology. The adoption of block chain and smart contract technology will bring significant benefits to both consumers and prosumer in a decentralized a smart grid(Tsao & Vu, 2021).

The use of smart grids can enable up to 100% uptake of renewable energy in the local micro-grids. When used in micro grid application, smart grids can make it possible to realize up to net (Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2021a)zero the exchange between a local micro grid and utility grid even when we have high variability and intermittence of the renewable sources of energy particularly wind and solar.

By facilitating efficient monitoring and feedback between consumers, producers, the utility and other stakeholders within the grid system, energy costs and unnecessary consumption and overloads can be avoided and achieve energy balance at micro grid as a benefit of enhanced monitoring of energy flows, electricity demand and power generation, power generation enabling a high level of energy flexibility(Kabeyi, 2018; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2021b). Through provision of optimizing capacity, use of smart grids facilitates cost reduction of the cost of energy or electricity.

Smart grids can deal with many current issues with the traditional grid by application of cutting-edge technology with a plethora of chances to improve efficiency and reliability of power systems. However, several socioeconomic and technical can hinder there deployment and applications(International Renewable Energy Agency, 2019). Since the grid is a complex architecture, decentralization by use of smart grids brings tremendous benefits at a cost. However, digitalization and integration of a large number of growing users makes smart grids soft targets for cyber-attacks and breach of confidentiality among other limitations(Skopik & Smith, 2015). Smart grid technologies, although promising, have several challenges as summarized in Table 2 below.

Table 2. Challenges facing smart grids.

	Challenge	Causes and Impact	Solution/Recommendations
1	Cost challenges	The main cost elements in smart grid development are associated with the power transmission and distribution system, electricity metering, and critical technologies. In economic analysis and financial feasibility	A country's capacity to pay for the development cost for smart grid infrastructure is paramount which disadvantages developing countries. `Funding by international institutions can facilitate access to requisite funding for smart grids.
2	Cyber Security	Smart grids deployment across the value chain, increases points of interconnection with different information networks which exposes the system to threats of cyber-attack to important power management systems and infrastructure.	Cyber security can be achieved through standardization. It is necessary to identify weaknesses of the smart grids exploited by attackers through Smart Grid Systems Treats Analysis and by integration of Systems Security Threat Models
3	Interoperability	Interoperability facilitates connection of different parties to the devices and systems for proper interaction	The interoperability can be achieved through strict implementation relevant standards
4	Physical Security	There is risk to valuable assets and systems that are widely spread across the country of power system boundaries	Investment in facility security and proper sitting away from danger and keeping of intruders and risks through access control.
5	Privacy and Security Policies	Wide scale interconnectivity and system access including the growth of Internet of Things associated with smart grid development, privacy, and development rises privacy and confidentiality concerns.	Put in place security policies to establish relationships between the consumers, utilities, generating companies, transmission firms, and third parties, although applying security and privacy policies
6	Connectivity	Refers to communications connectivity and interchange within the smart grid infrastructure and between users or stakeholders.	It is necessary to develop internet and communications infrastructure across the whole power system coverage area.
7	Confidentiality challenges	Access Control and Identity Management is needed for confidentiality of data transmitted via smart grids.	Only authenticated users should be allowed access to the control center for transmission, and distribution grids
8	Defence	The smart grids have inherent vulnerabilities against which it must be protected. This can be achieved by building an effective, layered defence system for protection of the smart grid infrastructure.	This defence or protection against the threats or vulnerabilities give the network segmentation and access control to defend against denial-of-service (DoS). Technologies used include firewall, virtual private

			network (VPN), intrusion prevention system (IPS).

From Table 2, challenges facing smart grids include high cost of investment and limited access especially for developing countries having multiple socioeconomic challenges, interoperability of standardization related issues, cyber and physical security, communication and internet connectivity challenges and high system security requirements.

6. Conclusions

Smart grids apply digital technology to avail electricity in the form of an extensive cyber-physical power system which can enable controllability and responsiveness of decentralized electricity generation and supply within the overall power grid system. The Smart grid is a technology of the future whose primary objective is to reduce costly peak demands, maximize absorption of variable renewables and reduce energy related greenhouse gas emissions and facilitates dynamic pricing which enhances consumer awareness and participation in power generation and consumption. Advances in smart grids will add value to electrification of transport making millions of cars not just exist as variable loads but act as renewable energy storage devices and sources of decentralized power for grids... The Smart grid is the direction and trend of power industry development based on physical grid and that combines advanced information & communication technology with operation technology the traditional grid to form a smart system. The main links covered by the smart grid are power generation, transmission, system transformation, power distribution, electricity consumption and dispatch. The smart grid coordinates the needs and functions of different participants in the grid environment enabling the system to operate on the premise of ensuring system reliability and stability. The smart grid technology is a product of the fourth industrial revolution (4IR) which is important to achieve fastest technological reformations in electricity generation, transmission, and distribution (T&D) because of growing application of computers, sensors, sensors, and communications. In this study, the use of smart grids in electrification of transport and related products and services including vehicle to gris (V2G), G2G are presented. By plugging abilities and Thing (IoT), Smart grids can optimize energy solutions through flexibility in the management of the diverse energy systems, enhance operational insights, improve maintenance forecasting and self-healing abilities, and create a more secure and safe power system. Smart grids enable power utilities and grid operators to effectively monitor the electricity usage of electric vehicles in real-time, which makes it easier to balance the load on the grid and reduce peak demand and provide an opportunity to optimize the charging of electric vehicles.

The smart grid applies wireless sensor networks (WSNs) communication technologies which are cheaper, faster to deploy, enhances flexibility, and aggregated intelligence via parallel processing capabilities. The internet of Things, which is a characteristic feature of smart grid systems refers to the application of wireless sensor networks (WSNs), smart meters, actuators and components with information and communication technology (ICT) in operations. The main limitation or challenge with integration of the IoT technology within the smart power grid is the introduction of costly large data processing. The data handled within the smart grid system includes end users load demand, faults on power lines, status of network components, scheduling energy consumption, forecast information and conditions, records on advanced metering, outage management records, and records of enterprise assets.

Smart grids will play a very important role in the ongoing transition from centralized power systems to decentralized systems whose control is influenced by dynamic market forces for investment, operational stability and reliability and facilitate greater absorption of variable electricity like solar and wind as well as variable loads like electric vehicle battery recharging system and related products like V2G and G2V. A sustainable electricity mix and power system will require seamless coordination of both centralized and decentralized power generation and distribution. Therefore, to achieve sustainable development requires electricity systems to adequately respond dynamically, and intelligently to change in demand and supply. This will facilitate energy security, and power quality which are requirements for realization of technical, economic, and environmental performance sustainability. Therefore, smart grids will transform the power sector into a desirable system with reliability, availability, and efficiency, which are requirements for improving the world economy and guarantee environmental protection. However, the transition period requires tests, technological innovations and improvements, consumer education, development of appropriate or requisite standards and regulations, and information sharing or networking between all players in the energy sector to ensure that the benefits of smart grids will be realized globally for all humanity.

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