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SUSTAINABLE RESEARCH FOR ENERGY AND ENVIRONMENT

Applications of smart grid technology in Nepal: status, challenges, and opportunities

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Abstract

Energy transformation and sustainability have become a challenge, especially for developing countries, which face broad energy-related issues such as a wide demand–supply gap, extensive fossil fuel dependency, and low accessibility to clean energy. Globally, smart grid technology has been identified to address these affairs and enable a smooth transition from traditional to smart energy systems, ensuring energy security. This paper studies the critical role in strengthening the power system, integrating renewable sources, electrifying the transport sector, and harnessing bioenergy. Evaluating the current energy scenario in Nepal, this article presents the smart grid as a solution to existing and future energy issues and the associated challenges during its implementation, urging concerned authorities to launch initiatives to promote it. Moreover, this study also lays the foundation for future research into the smart grid's potential to reform the power sector in other developing nations with abundant renewable energy sources and similar energy-related barriers.

Keyword Smart grid technology · Microgrid · Renewable energy · Energy transition · Challenges · Nepal

Introduction

Non-renewable resources such as fossil fuels are finite. Their continued use has evident health and environmental consequences owing to greenhouse gas (GHG) emissions, air pollution, water pollution, land degradation, and waste production (Yadav et al. 2020). To solve these issues, long-term initiatives aimed at achieving global sustainable development are required (Gorjian et al. 2019). However, a country's social and economic growth would be impossible without effective administration and the use of existing renewable energy sources (RESs) (Gorjian and Ghobadian 2015). Therefore, having access to renewable energy has become

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Highlights

- Applications of smart grid technology can significantly reduce GHG emission in the future.
- Smart grid is necessary to support the transition from fossil fuels to renewable energy.
- FACTS and RACDS technologies are crucial in overcoming existing shortcomings.
- Opportunities are through microgrids, electric vehicles, and wastewater treatment.
- High capital cost and lack of policy restraint in smart grid implementation.

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decisive in achieving social, environmental, and economic progress. Nepal is one of those developing nations which is currently underutilizing its potential RESs: with a per capita electricity consumption of 267 kilowatt hours (kWh) in 2020 (Himalayan News Service 2020). Therefore, there is a need to modernize the conventional energy system, following the path of other developed/developing countries to meet respective energy targets.

According to International Renewable Energy Agency (IRENA), the share of renewable energy in total global electricity production should increase from 33.3% in 2018 to 85% in 2050 to restrict global average temperature rise below 2 °C, as mentioned in Paris Climate Agreement 2015 (IRENA 2018). At the end of 2020, the total renewable energy capacity reached 2799 Gigawatts (GW) globally, and its share in total production has increased from 33.3% in 2018 to 36.6% in 2020. Hydropower (1,211 GW) provided the largest renewable share, with the wind (733 GW) and solar photovoltaic (PV) (714 GW) accounting for the majority of the remaining share (IRENA 2021a). China (31.97%), the United States (US) (10.43%), Brazil (5.36%), India (4.79%), and Germany (4.72%) (Fig. 1a) each contributed a significant part of the global renewable energy generating capacity (IRENA 2021b). Globally, renewable energy generation capacity has been significantly rising yearly (Fig. 1b) because of the advancement of smart technologies, encouraging the integration of RESs like solar PV and wind power via the transformation of conventional grids into smart grids.

The energy transition from non-renewable to renewable has been emerging as a global energy plan (Fuentes et al. 2020). Therefore, the average annual rise of global renewable energy consumption has been significantly increased by 8.62% (Fig. 1b). Heavy dependence on conventional

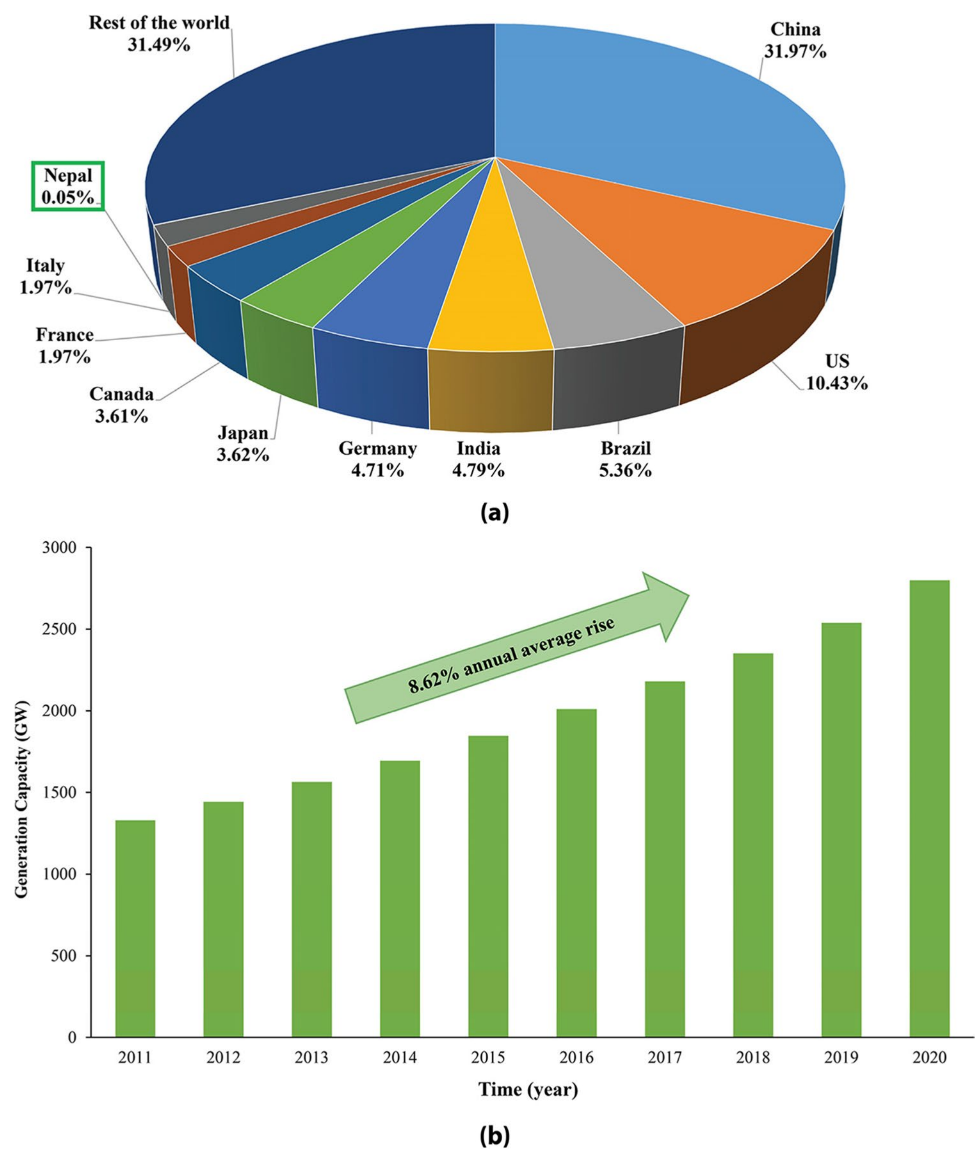


Fig 1 **a** Global share of renewable energy 2020, and **b** Globally generated annual renewable energy over the past years (Data Source: (IRENA 2021b))

fuels has raised concerns over environmental and socio-economic sustainability (Sovacool et al. 2011); therefore, the focus of Nepal's energy policies needs to shift from traditional energy technology to smart and efficient energy technology. Hence, transforming existing power grids into smart ones is crucial to boost energy transition and achieve sustainable development goals. However, limited studies have evaluated the need for this technological shift, and few have recognized smart grid technology as a viable option for achieving Nepal's sustainable energy transformation.

Thus, the primary aim of this study is to offer a tool to assist Nepal's energy sector transformation/reformation. More specifically, this paper explores different technologies that aid in smart grid transition and management of micro-grids and aims to highlight the role of electric vehicles and wastewater treatment in promoting sustainable energy in the future. It discusses the technical, managerial, and legal barriers that emerge in smart grid implementation, and thus devises necessary solutions/roadmap that can be adopted to overcome them. Moreover, to achieve 2050's global target of 85% share of renewable energy in total electricity production, all developing countries should emphasize efficacious incorporation of their available RESs through making their grid flexible and innovation-friendly by adopting a smart grid strategy. Therefore, this paper highlights and encourages its essentialness and opportunities in developing countries like Nepal for achieving the global goal of a sustainable and clean energy future. Finally, based on the findings in the context of Nepal, this study proposes suitable policies and institutional frameworks that can be relevant to transforming energy sector in developing countries, and thus also suggests prioritization of investments in Renewable Energy Technologies (RETs) in the future.

For the literature review, the "Google Scholar" search engine (scholar.google.com) was used, and research articles, mostly after the year 2000, were reviewed. Keywords like "smart grids," "renewable energy," "technology," "hydropower," "solar power," "wind energy," and "sustainability" etc. were used for the search. Data and energy status were reviewed through National Electricity Reports and thoroughly compared with National Reports from other countries like India, Bangladesh, and Brazil. Moreover, secondary data regarding current global energy scenarios, electricity demand and capacity, and transmission network in Nepal were obtained from IRENA, Water and Energy Commission (WECS), and World Bank, respectively. Reports from Asian Development Bank as well as relevant literatures were also analyzed to discuss the status of the development of some technologies, as well as to underline some key issues and barriers in those realms. Finally, National Policy Reports were reviewed, and the policy implications of smart grid technologies were discussed alongside the managerial implications.

Smart grids

The term Smart Grid was, presumably, first coined in a paper titled "Toward a smart grid: power delivery for the twenty-first century" in 2005 (Massoud Amin and Wollenberg 2005). The Smart Grids European Technology Platform has defined a smart grid as "an electricity network that can smartly integrate the actions of all users connected to it — generators, consumers and those that do both—to efficiently deliver sustainable, economic, and secure electricity supply" (Vesnic-Alujevic et al. 2016). Some European countries and the US realized the necessity of modernization of the power grid in the 1980s and made significant progress in transforming the smart grid (Simões et al. 2011). In contrast, developing countries like Nepal have only recently realized its need to effectively manage produced energy, reduce power loss, and appropriate utilization of potential RESs.

Global perspective

Smart Grids have been globally popular since the mid-2000s and progressively developed worldwide, most remarkably in the US, the UK, Italy, Japan, and South Korea. During the initial phases of smart grids development, the US and the European Union (EU) aired numerous pilot projects, deploying smart grid applications such as smart meters, electric vehicles (EVs), distributed generation, smart network management, etc. (Simões et al. 2011). Currently, they are focused on increasing energy efficiency and RES inclusion, bolstering and broadening their linkage between countries and states (Ponce-Jara et al. 2017; Gorjian et al. 2021). Despite China being a latecomer to smart grid deployment, its expenditures on smart grid projects mainly focused on high-voltage transmission networks have already surpassed those of the US. Meanwhile, developing nations India and Brazil are investing/advancing their efforts to transform their grid by initiating many developments and reform programs with the formation of various commissions, regulations, and acts (Asaad et al. 2019; Dranka and Ferreira 2020). Their programs include installing smart meters, applying geographic information systems in distribution networks, and energy derivation from alternate sources. Their efforts are chiefly converged to electricity theft detection and loss reduction (Ponce-Jara et al. 2017).

Bangladesh and India are also facing various power supply issues. With heightening demand and dependence on coal- and oil-based power plants, Bangladesh is susceptible to the heavy blow from the ongoing energy crisis (Uddin and Taplin 2006). The ongoing affairs of its power system are poor and aging power system infrastructure, limited fossil fuel resources, high losses, low renewable energy usage, and high GHGs emissions. The Government of Bangladesh and its distribution companies have been inclined toward smart grid technology to incorporate available renewable sources in the primary grid and thus helps reduce dependence on carbon-intensive fossil fuel plants (Islam and Bloemink 2018). Facing similar problems, India has also been implementing smart grid technologies for energy security, limiting global warming, strengthening the renewable energy sector, and escaping the energy crisis (Singh and Tiwari 2017). Furthermore, the global trend of increasing renewable energy capacity over the previous decade (Fig. 1b) justifies the need for Nepal to make the transition toward smart grid technology.

The current scenario in Nepal

In Nepal's current power system, fragile transmission and distribution network, aging infrastructure, high transmission and distribution loss, power theft, poor RESs penetration, and heavy reliance on fossil fuels are significant concerns that need to be addressed promptly (The Kathmandu Post 2018). The Nepal Electricity Authority (NEA), to alleviate these issues, intends to set up 5 million smart meters in stages by 2025. It had intended to station 98,000 smart meters in two distribution centers in Kathmandu Valley (KaV) by May 2020 and 450,000 smart meters in 10 distribution centers in KaV by May 2021. However, due to complexities caused by the COVID-19 pandemic, only around 60,000 smart meters have been deployed, but still, immediate benefits like lower meter reading costs and reduction in losses have been realized in the early phases. Furthermore, it projects to set up a total of 3 million smart meters by May 2023 and 5 million smart meters by May 2025. Along with this, NEA has a target to take up several pilot projects (ADB 2018). It has started the Kathmandu Valley Substation Automation Project to make the grid system more reliable and smart, as well as lower operating costs and improve equipment service life. In addition, numerous high-voltage transmission lines (400 kV) have been finished, and others are now being built or proposed (NEA 2021).

Recently, NEA has taken the initiative to install 50 EV charging stations in essential places and highways across the country in response to the government's plan and policies to increase the share of EVs. On April 09, 2021, a contract was signed with M/s Wanbang Digital Energy Co., Ltd., China, with 1 year estimated time of completion, with the preconstruction survey work ongoing currently. Moreover, NEA has plans for extending the number of charging station up to 300 shortly (The Himalayan Times 2021). Regarding utilization of RESs, Nepal's first large-scale private-owned solar power plant of capacity 8.5 Megawatt (MW) was connected to the national transmission line by Ridi Hydropower Company in Butwal (Bhusal 2020). Additionally, the Government of Nepal (GoN) has issued construction licenses to 15 solar power projects amounting total capacity of about 92 MW (DoED 2021). Geotechnical investigations and hydrological studies are currently underway in the Begnas-Rupa Pump Storage Hydroelectric Project (150 MW), while a Memorandum of Understanding (MoU) has been signed for the Environmental Impact Assessment (EIA) and geotechnical studies in the Kulekhani-Sisneri Pump Storage Hydroelectric Project (100 MW) (NEA 2021). Furthermore, the Department of Electricity Development (DoED) has granted licenses to many pump hydro-storage projects. The GoN and related authorities have established numerous policies and regulations in past years that promote various smart grid concepts as presented in Table 1.

These initiatives and policies indicate that GoN and relevant stakeholders have realized the need to modernize and upgrade the power system. Still, progress is slow due to their complicated physical and socio-economic aspects. Therefore, the future trend is restructuring the Nepalese energy sector through smart grid technology to provide a high degree of energy security and reliability, which requires in-depth discussion and analysis concerning its massive potential and benefits and associated challenges.

The necessity for smart grid in Nepal

Nepal's gradually improving economy needs safe access to modern energy technologies to exploit/utilize its vast RESs for long-term growth and prosperity. Therefore, transformation to smart grid technology is required to make better use of current infrastructure and include new technologies in the future. The main driving forces that necessitate Nepal's smart grid transition are addressed in the following sections.

Meeting the rising demand

In the past, the shortage of energy resulted in frequent and irregular power outages and load-shedding up to 12–14 h per day. It led to losses of about US$24.69 million yearly in the industrial sector (Poudyal et al. 2019). It was facilitated through preliminary strategy and plan adopted by NEA and GoN to mitigate the crisis by controlling electricity loss and increasing performance of electrical energy system (ADB 2017). The NEA has managed to reduce the losses from 25.78% in FY 2015/16 to 17.18% in FY 2020/21 (NEA 2021), but still, it is almost double when compared with the average world loss (8.25%) (The World Bank 2018). Compared with some South Asian countries, loss in India is about 20% (The Economic Times 2021), 11.8% in Bangladesh (BPDB 2019), and 8.34% in Sri Lanka (CEB 2018).

Table 1 Key policies/regulations in Nepal related to smart grid concepts with their status

Smart grid concepts	Policy/Regulation in Nepal	Status	References
Advanced metering infrastructure (AMI)	•NEA completed cybersecurity audit and assessment frameworks for smart meter deployment •The Nepal Telecommunications Authority (NTA) allocates an adequate spectrum in the sub-gigahertz frequency ranges for machine-to-machine and other Internet of Things (IoT) in the smart metering, smart grid, and smart city sectors applications •The Bureau of Standards, under the Ministry of Industry, developed national standards and specifications for smart meters and advanced metering infrastructure functionality (AMI) •NEA developed successful consumer outreach campaigns to encourage customers to take an active role in smart meter installation	In the early phase of planning and implementation Phase I of the pilot project is completed	ADB (2018)
Demand side management	•NEA launched an initiative, "Bright Nepal, Prosperous Nepal," to promote efficient light-emitting diode (LED) bulbs instead of incandescent and tungsten bulbs to reduce peak demand •NEA developed a policy to install time of day (TOD) meters for commercial and industrial consumers, enabling a high tariff rate to discourage high energy usage during peak hours •NEA started periodic revision of TOD tariff rates to reduce the peak demand	Not effective and limited progress	Shrestha and Nakarmi (2015)
Renewable energy and distributed generation	•The Renewable Energy Subsidy Policy, 2016, based on project appropriateness and socio-economic advantages, has offered a subsidy to pay 40% of the entire costs of renewable energy technologies such as small/micro/pico hydropower, solar mini-grids, biogas, biomass energy, and wind energy •The White Paper, 2018, prioritized the development of renewable energy technologies, data mapping, and the collecting and analysis of national-level information and statistics •Budget Statement of Fiscal Year (FY) 2021/22 has declared to provide 90% subsidy for electricity connection via micro and small hydropower, solar power, and wind power to 50,000 households not connected to the national grid •Fixed Power Purchase Agreement for hydropower projects: wet season: Rs. 4.80/kWh; dry season: Rs 8.40/kWh with annual increment of 3% for the first eight-year	In the Implementation phase and penetration of RESs are increasing	MoPE (2016); GoN (2018a, 2021)

Table 1 (continued)

Smart grid concepts	Policy/Regulation in Nepal	Status	References
Energy storage technology	•Budget statement of FY 2021/22 has emphasized the development of storage hydropower plants to supply domestic demand during the dry season. Higher returns will be provided to storage projects with multiple benefits	In the early phase of conceptualization and planning	GoN (2021)
Electric vehicles	•Budget statement of FY 2021/22 has: •Decreased customs duty on import of EVs from 80 to 10%, along with zero excise duty on them •Declared to waive renewal and road taxes for 5 years if an existing fossil fuel vehicle switches to electric •Environment-Friendly Transport Policy, 2014, aims to advance the EV manufacturing sector to enhance local job opportunities, lower production costs, and stimulate the use of local resources •National Transport Policy 2001 includes the provision for electric rail service, utilizing hydropower	Implementation phase Two- and three-wheeler EVs are mobilized in some cities	GGGI (2018); GoN (2021)

The critical factors for creating such a wide demand–supply gap throughout the past years were primarily attributed to incompetent plans to diversify generation, transmission, and distribution systems and setbacks in project completion in time. In recent years, by promoting local production, import, and effective demand-side management via coordinated resource utilization, Nepal has successfully annihilated load-shedding. Still, it persistently continues experiencing the antagonistic effects of inadequate and inconsistent power supply due to various problems depicted in Fig. 2. Furthermore, the total generation capacity has increased gradually from 706 MW in 2011 to 1900 MW in 2021, while the peak demand has overgrown from 946.10 to 1500 MW (ADB 2017; NEA 2020, 2021; DoED 2022).

If not resolved by adopting an appropriate strategy in time, these problems will surely make the energy system of Nepal more vulnerable to a broad demand–supply gap and frequent power failures when required to meet the high demand in forthcoming years. Water and Energy Commission Secretariat (WECS) has modeled electricity demand for 25-year planning period under different scenarios as depicted in Fig. 3. The higher the GDP growth rate, the higher will be the demand. Also, the same study has projected the installed capacity required, as presented in Fig. 4, to meet the electricity demand in the corresponding scenario. According to the World Bank, the annual GDP growth rate was 6.657% in 2019 (The World Bank 2020), so we expect it to reach a high scenario soon. To meet such high demand, the existing power grid of Nepal needs sheer modernization to ensure better management of produced energy, reducing losses to acceptable limits, utilization of domestic resources curtailing import, and a flexible distribution system.

Electrification of the transportation sector

The transportation sector is among the rapidly expanding sector of Nepal, which is responsible for consuming a significant portion of fossil fuel and GHGs emissions. The percentage of fuel consumed by the transportation sector in total fuel consumption has jumped from 49% in 2007 to 67% in 2017 (Zhou et al. 2020). With a rise in consumption, the emission of GHGs like CO_2 has also elevated inexorably. In 2017, 45.4% of overall CO_2 emission was released by the transportation sector in Nepal (Zhou et al. 2020). Such emission has contributed to air pollution and global warming, which have a deteriorating effect on human health and the environmental ecosystem (Shrestha et al. 2017).

Therefore, to restrict the rising GHGs discharges from carbon-intensive technologies, it is suggested that the nation should take essential activities to shift to alternative low carbon technology. Electrifying the transport sector would be a sustainable solution to restrict GHG emissions (Kainuma et al. 2017). But the current scenario is quite the opposite,

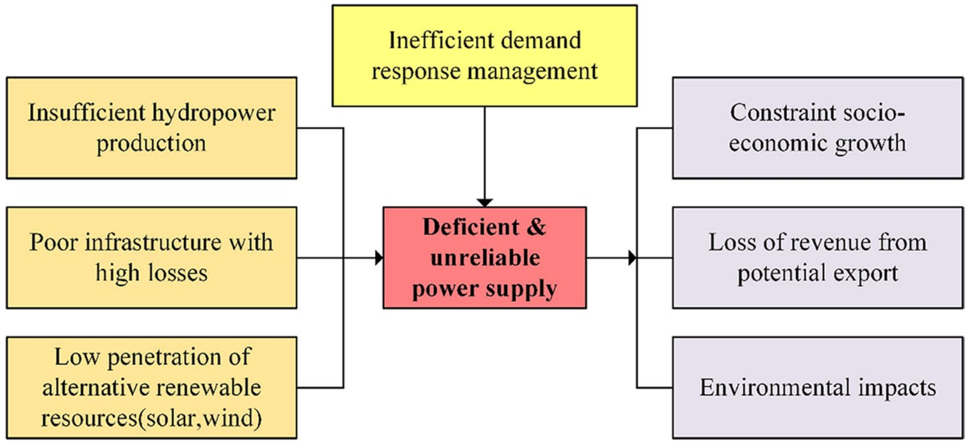


Fig. 2 Key causes and consequences of Nepal insufficient and unreliable power supply (Data Source: ADB 2017)

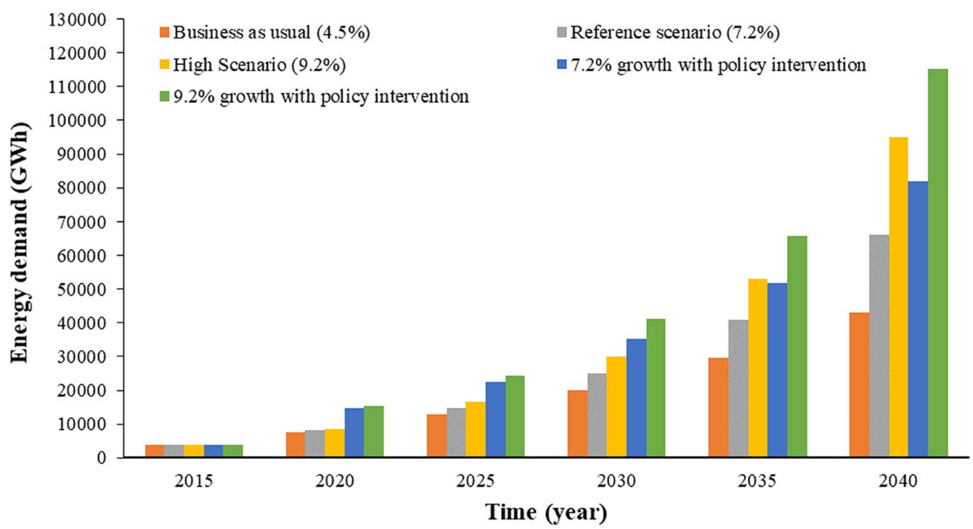


Fig. 3 Electricity demand at different scenarios with predicted ones (Data Source: (WECS 2017))

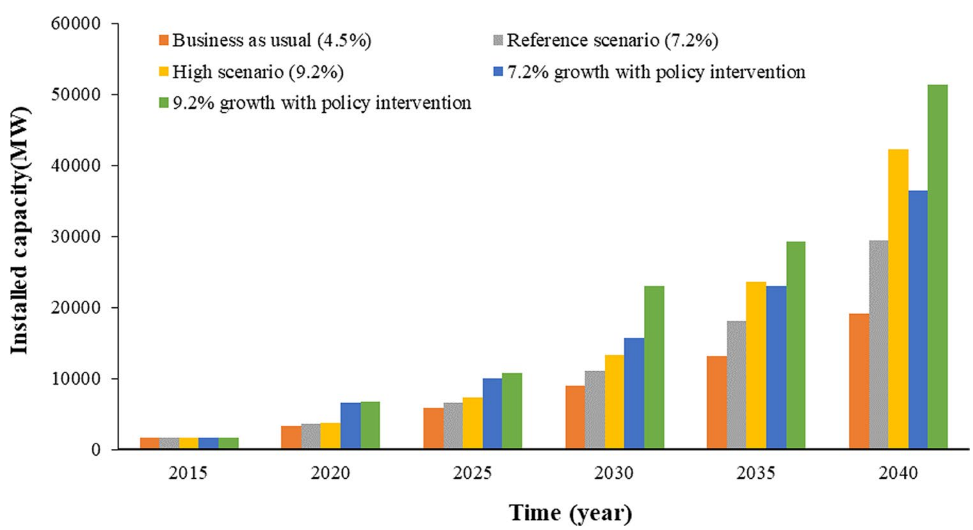


Fig. 4 Required installed capacity under different scenarios with predicted ones (Data Source:(WECS 2017))

where imported oil products fully fulfill energy demand in the transport sector. Electricity shared only 0.06% of the final energy consumption of the transport sector, whereas oil products shared 99.94% in 2017 (Zhou et al. 2020).

To improve this situation, the Ministry of Physical Infrastructure and Transport, in association with the United Nations Center for Regional Development (UNCRD), has devised National Sustainable Transport Strategy (NSTS) with an insight to develop a transport system that is "efficient, accessible, people-centric, affordable, reliable, safe, inclusive, environmentally friendly, and climate and disaster-resilient" (Acharya et al. 2015). To mitigate climate change, Nepal's Nationally Determined Contribution (NDC) is a mechanism under Paris Climate Agreement 2015 in which it agrees to manage climate change and has four targets linked with the transport sector shown in Table 2. GoN has formulated and implemented several provisions and policies for electric mobility and the sustainability of transportation systems (GGGI 2018). By reducing the tax imposed on EVs, GoN has prioritized and published optimistic intentions to promote them.

Rural electrification

Because of rugged terrain and socioeconomic hindrance, the extension of the national grid line to rural areas has been challenging. Almost three-quarters (72.84%) of total final energy consumption comes from traditional energy sources like firewood, agricultural waste, biofuel, etc., while electricity contributes only 3.66% in total consumption (IEA 2019). As per NEA, nearly 87% of households all over the country have electricity access through the national grid line. In rural areas not directly connected to the national grid, GoN, in association with Alternative Energy Promotion Centre (AEPC), has been providing electricity service through distributed sources like solar PV, wind, and micro-hydro power (MyRepublica 2020). However, those sources cannot resolve the rural electrification problem due to seasonal discrepancies in generation capacity and demand fluctuation. Those shortcomings can be overcome if distributed sources are integrated by establishing community-scale micro-grids and hybrid power plants combining various available sources. Bhorleni village in Makwanpur district has a hybrid plant aggregated with 15 kilowatts (kW) solar and 10 kW wind power, which supplies electricity to 131 houses at a minimal cost. Besides, a 12 kW solar-wind hybrid plant has been established in Dhaubadi Village of Nawalparasi district (Poudyal et al. 2019). Nepal has considerable potential for such distributed generation and hybrid system, shown in Table 3, which can contribute to filling the demand–supply gap of the village and the whole country if they are appropriately interconnected to the national grid line.

Transition into smart grid

It is fundamental to figure out the shortcomings of Nepal's existing transmission and distribution networks to assure a smooth transition into the smart grid. Figure 5 presents Nepal's power transmission network map with an existing and proposed network, reflecting the inhomogeneity of transmission networks distributed across the country. Major hydropower stations, the primary sources of electricity, lie in the Himalayan region due to abundant perennial rivers. However, the main load centers like industries, commercial zones, and large apartments lie far from generating stations

Table 2 Nationally determined contribution targets in addressing the transport sector in Nepal (GoN 2016)

Target	Description
NDC Target 9	To raise the percentage of EVs to 20% by 2020, up from 10% in 2010
NDC Target 10	To reduce reliance on fossil fuels in the transportation sector by 50% by 2050 via adequate mass public transportation and the promotion of energy-efficient EVs
NDC Target 11	To build an electrical (hydro-powered) rail network to enable mass commodities and public transportation by 2040
NDC Target 14	By 2025, to reduce air pollution by properly monitoring sources of pollution such as outdated and poorly maintained automobile

Table 3 Renewable sources with corresponding potential energy (AEPC 2008; Surendra et al. 2011)

Source	Technical potential	Economic potential	Remarks
Major hydropower	45,610 MW	42,133 MW	Considering the major river basins
Mini-/micro-hydro	> 100 MW	–	Viable in 55 districts
Concentrated solar power	1829 MW	–	> 4.5 kWh/m^2/day radiation and 2% country area
Grid-connected PV	2100 MW	–	> 4.5 kWh/m^2/day radiation and 2% country area
Wind	3000 MW	–	Assuming 10% area with more than 300 W/m^2
Biofuels	100,000 tons	–	Assuming 10% area with more than 300 W/m^2

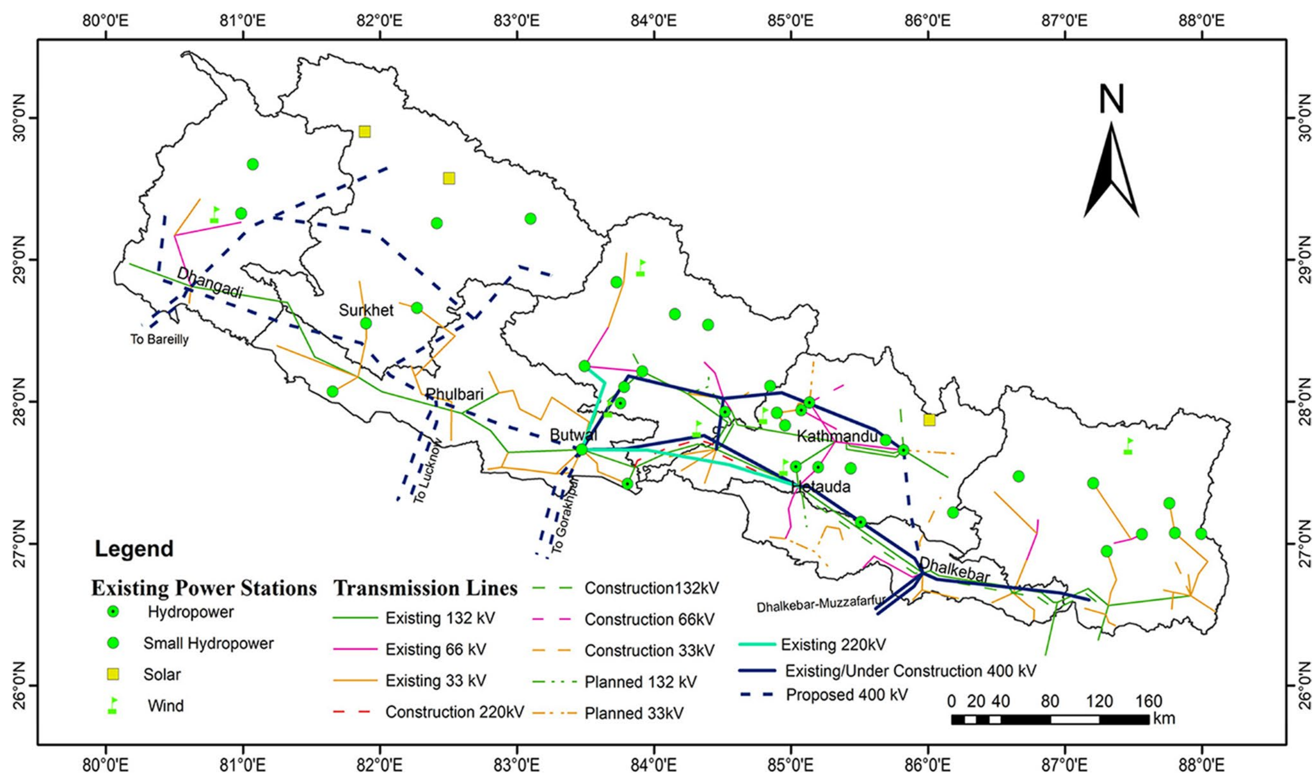


Fig. 5 Power transmission network map of Nepal, 2020 (Data Source: (The World Bank 2013; RPGCL 2020))

requiring longer transmission lines to fetch the required power. It is congested in commercial and industrial regions like KaV, Butwal, and Hetauda, and scattered sparsely in other areas. About 75% of the long transmission lines, as of 2019, operate at 132 kV. Only about 12% of transmission lines operate at 220 kV or higher, resulting in transmission loss of 4.64%, higher than the acceptable limit of about 2% (NACAA 2015). With the ever-increasing penetration of RESs and aging infrastructure, it becomes arduous to maintain grid stability and flexibility with existing transmission infrastructure. Moreover, an increase in the cost of acquiring high voltage transmission lines and disproportionate congestion areas due to lack of control also poses as restraints.

For transforming into a smart grid system, these issues need to be rectified by introducing Flexible AC Transmission System (FACTS) and Resilient AC Distribution System (RACDS) technology (Zhang et al. 2012). Some of the critical roles of FACTS and RACDS for transition into the smart grid in Nepal are illustrated in Fig. 6.

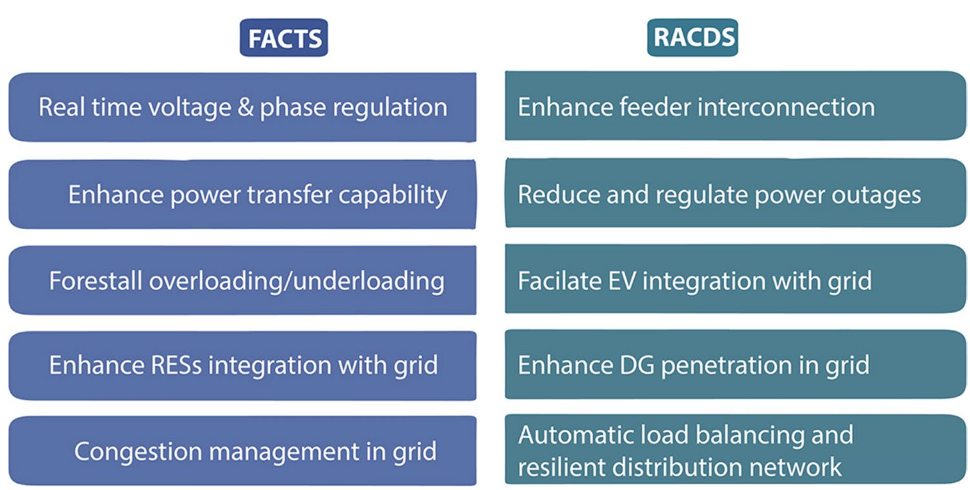


Fig. 6 Roles of FACTS and RACDS in transition into a smart grid in Nepal

FACTS and its configuration

The Institute of Electrical and Electronics Engineers (IEEE) has defined FACTS as "a power electronics-based system and other static equipment that provide control of one or more AC transmission system parameters to enhance control- liability and increase power transfer capability" (Edris et al. 1997). In the existing grid of Nepal, it is impossible to control different electrical parameters like impedance, phase angle, and magnitude of voltage in real time, which constrain the grid flexibility. But with FACTS devices and controllers, these parameters can be altered and composed in real time, offering a new level of opportunity for managing the network.

To control power flows, Nepal's AC grid system has been designed to incorporate mechanically switched series and shunt compensation along with voltage regulating components and phase-shifting transformers. To achieve a smooth transition into the smart grid, these components should be replaced by FACTS devices that use power semiconductors for quicker reaction to disturbance than mechanical systems. Static Var Compensator (SVC) and Thyristor Controlled Series Capacitor (TCSC) are conventional FACTS devices based on thyrist or switched capacitors and reactors. But the advancement of power electronics led to the invention of voltage source converters (VSCs) hinged on gate turn-off (GTO) and insulated gate bipolar transistor (IGBTS) ensure modern FACTS devices-static synchronous compensator (STATCOM) and unified power flow controller (UPFC). These devices can manage active and reactive power flowing in the grid at steady and transient stages by controlling parameters like voltages, phase angle, and impedance (Abu-Siada 2017; Ghiasi 2019), reducing transmission losses and adding stability to the network.

To get assistance from FACTS, they need to be acquainted with the transmission network in specific configurations. Shunt compensation, series compensation, shunt-series configuration, and back-to-back configuration are different configurations of the FACTS devices in the smart grid. Peng and Wang (2019) discussed each configuration's role, functions, and limitations for maintaining grid stability, renewable energy integration, and power transferring efficiency. The same configurations are recommended for announcing FACTS in the transmission network of Nepal with adequate performance, economic, stability, and flexibility analysis. Table 4 presents commonly used FACTS devices with their functions and configurations, while Fig. 7 illustrates the transmission network with FACTS in the smart grid.

RACDS and its configuration

The architecture of the distribution network of Nepal is a primarily radial system, as shown in Fig. 8, due to which the entire feeder is interrupted in case of any faults-weather related or technical, and as a result, consumers connected to the whole feeder are unable to receive power. This underlines the fragility of the distribution system of Nepal, and therefore, transition into an intelligent grid is crucial to improve its resiliency. Similar to the FACTS, the concept to rejuvenate distribution system is summarized as RACDS, which enhances the resiliency of distribution system by engaging power electronics devices for distributed generation integration, voltage, and phase angle control to maintain a balance between active and reactive power and efficient load management (Peng and Wang 2019). Several studies and modeling analyses were performed worldwide, out of which integration of distributed generation, microgrid formation, and line hardening are the most common RACDS technology. Among them, microgrid configuration for enhancing resiliency, for its capability to incorporate distributed renewable sources and to operate in isolation, has been implemented most often in developed countries (Schneider et al. 2019).

Furthermore, the power grid can be made more resilient if locally generated and stored power from sole micro-grids is conveyed to end-users via a distribution system for which they need to be incorporated into the distribution network (Abbey et al. 2014). Also, due to the intermittency of renewable sources, lively variation of voltage and frequency is another critical issue (Pourmousavi et al. 2012). To facilitate it, devices and controllers like FACTS are provided at the distribution level, referred to as controllable RACDS devices. In-depth RACDS devices and their configuration like FACTS are discussed in Ref. (Peng and Wang 2019). RACDS interconnected distribution network within a smart grid is illustrated in Fig. 9.

Table 4 Fundamental Information about FACTS controllers (Zhang et al. 2012; Gandoman et al. 2018)

Devices	Technology	Functions	Configuration	Cost ($/KVAR)
SVC	Thyristor based	Regulate reactive power; control overvoltage; dampen power oscillation	Shunt	35
TCSC	Thyristor based	Dynamically control line reactance; Improves transient stability of power system; limit fault current	Series	50
STATCOM	VSC	Control under voltage; enhance power transfer capacity; improve power quality	Shunt	40
UPFC	VSC	Improve transient stability; dampen power oscillation; improve voltage stability	Shunt-series	40

Fig. 7 Schematic illustration of the transmission network in a smart grid (modified after (Peng and Wang 2019))

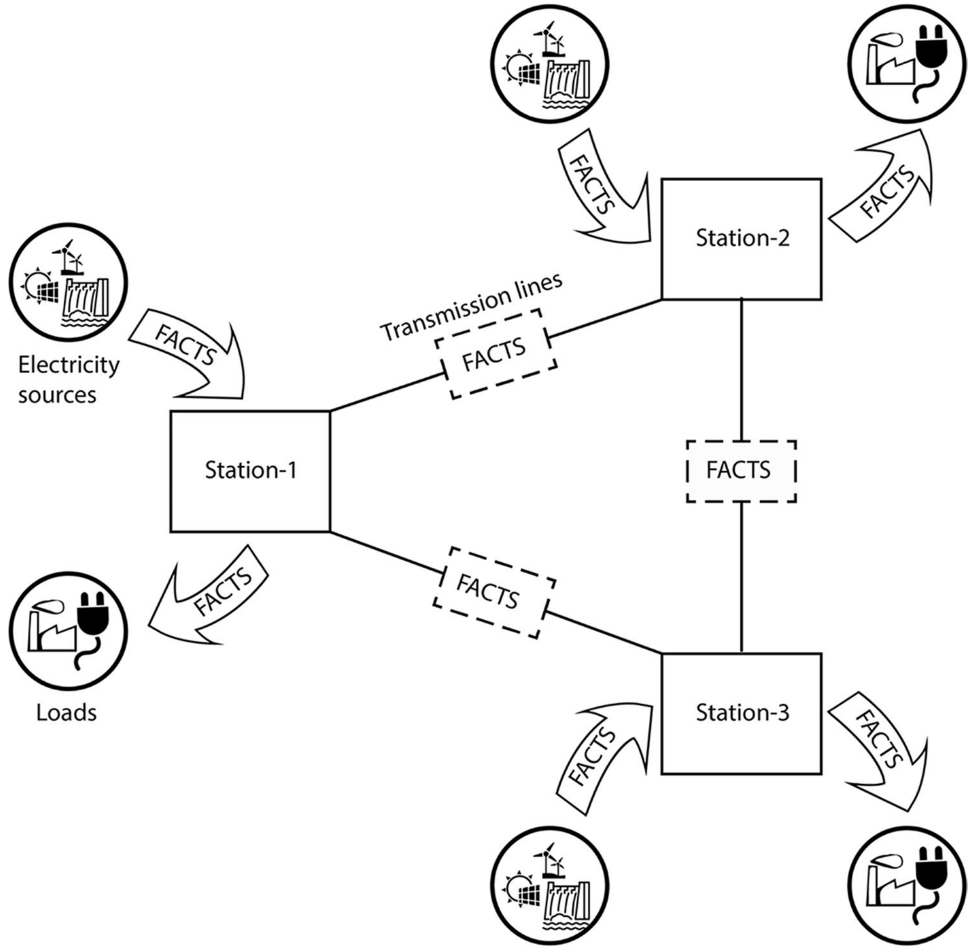
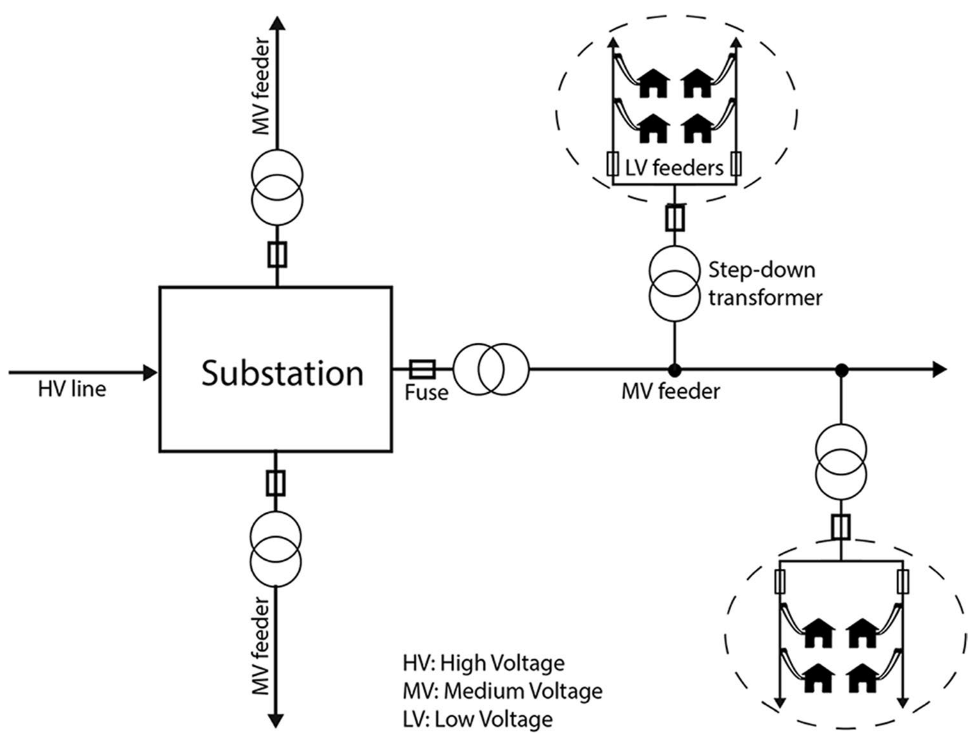


Fig. 8 Schematic illustration of a radial distribution network in Nepal



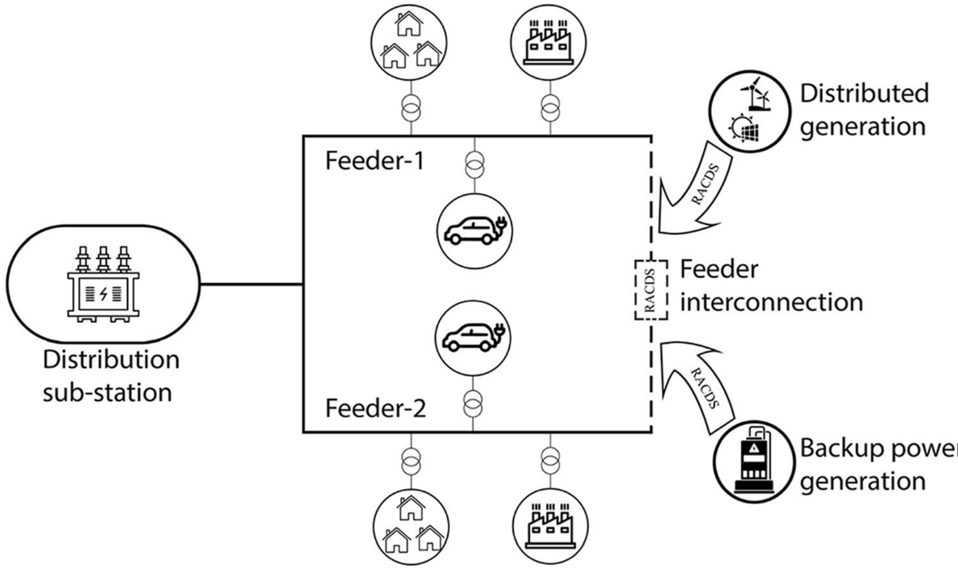


Fig. 9 Diagrammatic illustration of a distribution network in a smart grid (modified after Peng and Wang 2019)

Cost analysis and economic viability of FACTS/RACDS

The cost of FACTS devices comprises three primary components: inception/capital costs, operation and maintenance costs, and reliability costs. Inception or capital cost incorporates the cost of equipment (i.e., design, engineering, manufacturing, transportation) and construction (i.e., physical construction, erection, installation, and commissioning) of the FACTS controller. Furthermore, it includes the costs of land acquisition, existing power infrastructure modification, and the cost of building construction for housing indoor equipment (Duarte 2020). Figure 10 shows the structure of inception costs for the FACTS controller (Sung et al. 2000). The operating and maintenance costs generally include the costs associated with maintenance, services and monitoring, network utilization costs, equipment power losses, and insurance, which range from 1 to 5% of inception cost (L'Abbate et al. 2007). The cost of reliability is directly related to the cost of forced and unforced outages, i.e., benefits not accessible from the power system during outages. The cost of reliability may be determined by estimating this benefit, the average forced and unforced outage rate, and the time needed to return to service (Duarte 2020).

Furthermore, the cost of a specific FACTS device is dependent on device type and power rating, system voltage, administrative cost, ambient conditions such as temperature and pollution levels, and geography-specific physical limitations (Duarte 2020). Moreover, because of the need to import from other countries, their actual price in Nepal could be relatively high. The cost of conventional mechanically switched controllers ranges from US$15 to25 per

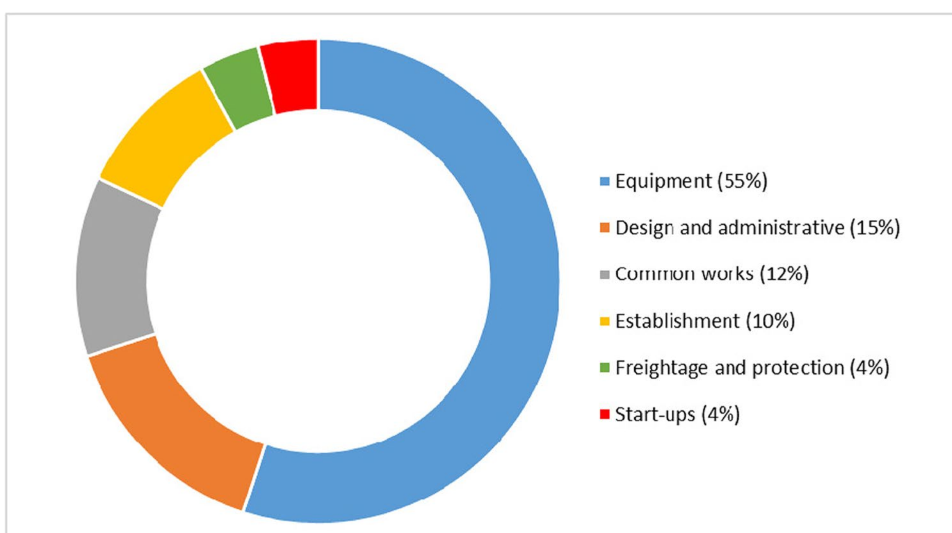


Fig. 10 Structure of inception cost for the application of FACTS devices

kilovolt-ampere reactive (KVAR) (Baldick and O'Neill 2009). Table 4 shows the average cost of some FACTS devices, and Table 5 provides the purchase and installation costs of various capacities (in megavolt-ampere reactive (MVAR)) FACTS devices (Gandoman et al. 2018). Therefore, FACTS controllers are more expensive than traditional mechanically switched control systems.

Blanco et al. has compared investment in traditional grid infrastructure with FACTS technology and suggests that the investments in FACTS are more efficient since they allow transmission grids to adapt to changing conditions (Blanco et al. 2011). In addition, FACTS enable economic distribution of produced electricity by enhancing capacity and better utilization of existing infrastructure while reducing losses and likelihood of fault occurrence. Thus, the installed FACTS controllers could be able to eliminate the need for new transmission lines, potentially saving a large amount of capital. Consequently, this will minimize the social and environmental impacts associated with the expansion of the transmission line (Acharya et al. 2005). Similarly, the costs and benefits associated with RACDS devices/controllers are comparable to that of FACTS. Therefore, the economic viability of implementing FACTS/RACDS technology in Nepal is justified by the technical merits, avoided monetary and non-monetary costs, and the possible direct and indirect advantages it provides in the energy and transportation sectors (Fig. 6). However, designers, operators, and utilities should undertake a rigorous financial and economic feasibility analysis before investing in FACTS/RACDS technology to develop a sustainable and efficient power grid.

Smart microgrid

Microgrids are small electrical networks that can be operated in isolated mode or grid-connected mode and have their storage units, whose size and capacity depend upon the extent of integrated distributed generation (Adefarati and Bansal 2017). In Nepal, several micro-grids comprising distributed renewable resources like micro-hydro, solar PV, and wind turbines are under operation in rural areas where the national grid line has not been reached yet. For example: Urja Upatkya Minigrid (107 kW) in Baglung, Thingan Minigrid (28 kW) in Makwanpur, solar-wind hybrid minigrid (35 kW) in Sindhuli etc. The various technical and management issues experienced by existing microgrids in Nepal are illustrated in Fig. 11.

Smart grid components can fix these issues, thus transforming them into smart microgrids by introducing smart technologies like energy storage devices, advanced metering infrastructure (AMI), smart appliances, computational intelligence, active demand response management, and the Internet of Things (IoT).

The rise in the integration of variable renewable sources makes energy storage devices an indispensable part of microgrids. The energy storage system improves the quality,

Table 5 Price of some FACTS devices (Gandoman et al. 2018)

Cost ($/KVAR)					Installation cost included
Type	100 MVAR	200 MVAR	300 MVAR	400 MVAR	
SVC	60	50	45	40	No
	100	80	70	60	Yes
STATCOM	90	75	68	60	No
	130	115	110	100	Yes

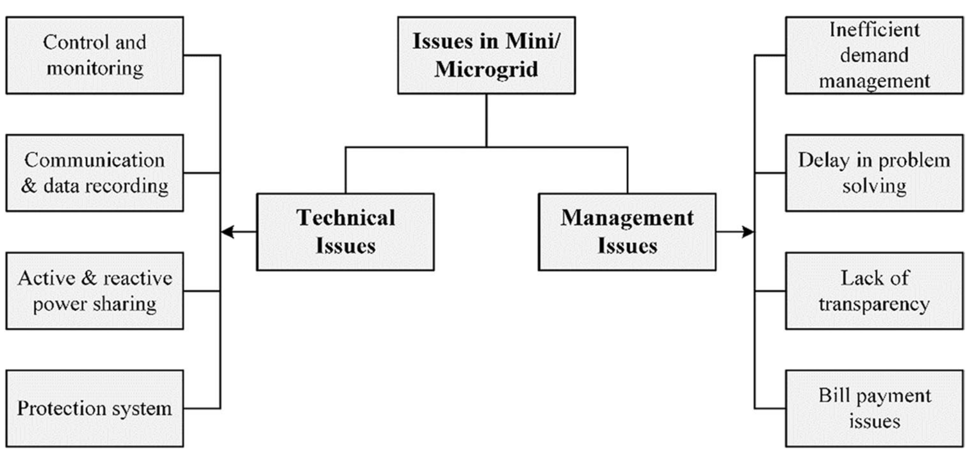


Fig. 11 Issues associated with the existing microgrids in Nepal (Shrestha et al. 2019)

reliability, and balancing of power in the grid and allows energy storage during non-peak hours and discharging during peak hours (Spataru and Bouffaron 2016). The disposition and incorporation of energy storage techniques like the flywheel, supercapacitors, advanced battery technology, and pumped hydro storage has provided a broad vision for smart microgrids (Abdi et al. 2017). AMI allows technology such as smart meters to facilitate a two-way exchange of information between consumers and utilities (Balakrishna and Swarup 2020). This would provide microgrids with a wide variety of capabilities, such as remote consumption control, time-based pricing, demand forecasting, theft and loss detection, and efficient revenue collection. Also, smart appliances or loads that allow two-way information flows with the grid improve power quality and reliability (Yan et al. 2017b). Various statistical and artificial intelligence methods for advanced forecasting of demand and variable RESs are crucial for smart microgrids to develop strategies for reducing the demand–supply gap and active demand response management (Yoldaş et al. 2017). With an increase in penetration of many distributed energy resources and interconnection of loads in microgrids, IoT solves the energy management, security, and power quality issue popup due to the increase in penetration of distributed energy resources and interconnected loads in smart microgrids (Birleanu and Bizon 2020). Furthermore, with the aid of these smart characteristics, the substantial reliability of EV charging stations can be achieved by efficiently and economically integrating them with community-scale microgrids, as discussed in Ahmad et al. (2019).

With the advent of smart features mentioned above, active demand response management can be achieved in the smart microgrids, thereby shifting peak load to an off-peak hour, reducing the undesired power outages, lowering the energy production cost, and bettering the power quality. Also, utilizing abundant distributed renewable resources with proper planning, study, and analysis, several such smart microgrids can be established in remote and urban areas of Nepal. Consequently, these smart microgrids can be integrated with the national grid to form a large-scale smart grid, thus making it flexible, resilient, reliable, and energy-efficient.

Electric vehicle in smart grid

Nepal has experience of running EV technology like trolleybuses and electric three-wheelers named "Safa Tempos" inside the KaV since the 1970s and 1990s, respectively. The trolley bus operation was terminated in 2011; however, Safa Tempos are still providing their service inside the KaV (GoN 2018b). Despite having an early start, Nepal has been unable to make any significant progress in electrifying the transport sector due to several barriers as discussed in Table 6. Many studies recommend some feasible solutions to overcome these hurdles; nevertheless, various practical factors may make implementation difficult (Table 6). Nepal is a landlocked country, and the country's harsh topography has made expanding the road network challenging. As a result, the requirement to import the bulk of materials and components, particularly without access to the cheapest form of transportation, namely, water transport, has stifled local industrial growth. In addition, several necessary mineral resources, such as lithium, iron, cobalt, nickel etc., have not been explored due to a lack of capital and technology (Paudel 2019). Furthermore, because the majority of remote areas lack access to roads and energy, the current distribution of EVs across the country is not uniform and concentrated in cities; for instance, Safa Tempos operate in KaV. Aside from these practical challenges, the GoN and relevant authorities have initiated some efforts to promote the transition to EVs, and the present state is included in Table 6. Moreover, the proposed initiatives/solutions for overcoming the barriers can be executed systematically and methodically by following the roadmap or framework depicted in Fig. 12.

Electric vehicles present both obstacles and opportunities for the power systems of Nepal. If charging activities co-occur with current consumption peaks, the possibility for increased peak energy demand may entail due to substantial EVs penetration. The uncontrolled charging of large-scale EVs results in significant voltage drop, overloading, and power loss in the distribution system (Luo et al. 2013). To alleviate these issues, one of the possible measures is to employ EVs as flexible/dynamic loads that can offer balancing services to networks with a high proportion of varying renewable energy supply (Kempton and Letendre 1997; Bibak and Tekiner-Moğulkoç 2021). To fully realize EVs' capability as a flexible or dynamic load, smart charging procedures must be employed.

Smart charging

Smart charging can occur in a centralized manner through aggregators or decentralized manner through decentralized control structures. In a centralized control structure, the optimal scheduling of each EV is handled by an aggregator. At the same time, in a decentralized system, each electric vehicle chooses its charging method without contacting the central controller or other linked EVs (Galus et al. 2013). In comparison to uncontrolled charging, both the centralized and decentralized systems may successfully decrease the energy costs and prevent the overloading of grid components by shifting peak demand to off-peak hours (Vaya and Andersson 2012; Patil and Kalkhambkar 2020). Although the centralized approach is more reliable and accurate and provides a more significant reduction in the GHG emission (Cheng et al. 2018), the scalability issues, the necessity for

Table 6 Barriers for EV adoption and recommended solution with current status in Nepal

Categories	Barriers	Recommended initiatives/solutions	Current status in Nepal	References
Technical barriers	•Range anxiety (one-time travel distance when fully charged) •Limited battery life •Long charging time •Increased power demand •Insufficient data collection and access	•Using Lithium-ion battery having higher charge density and longer life than lead-acid battery •Establishing battery swapping stations •Adopting fast charging technology •Using V2G/V2H technology to manage power demand •Establishing data collection and sharing protocol	•The private operators of "Safa Tempos" in KaV are in process of replacing lead-acid batteries by Lithium-ion	Quak et al. (2016); GoN (2018b); Ahmad et al. (2020); Amin et al. (2020); Khan et al. (2019b)
Social barriers	•Lack of consumer knowledge and awareness about environmental benefits of EVs	•Conducting campaigns, educational programs, advertisements, and technical exhibition about necessity and benefits of EVs	•Some consumers are well familiar with the pros and cons of EVs, while the majority are ignorant and see EVs as a luxury good •Proactive promotion of EVs is lacking	GoN (2018b); Panwar et al. (2019)
Economic and financing barriers	•Higher cost of infrastructure and purchase price of EVs •Higher electricity price for charging •Limited government incentive •Investor hesitation to invest in the EV industry •Limited human resources	•Financial institutions should make low-interest loans available for EV projects •Potential renewable sources like hydropower and solar should be utilized appropriately to lower energy prices •Establishing a national subsidy scheme •Public–private partnerships for fund •Creating favorable environment for foreign investment and sharing risk among stakeholders •Develop training program for engineers	•Public funding and low-interest loans are available in theory but difficult to mobilize •Hydropower projects are under development, and power is surplus in the rainy season. So, energy price is decreasing	GoN (2018b); Adhikari et al. (2020)
Infrastructure and market barriers	•Outdated grid infrastructure •Lack of charging infrastructure •Insufficient investment in facilities •Lack of domestic industry to manufacture EVs •Uncertainty of electric supply and cost •Under-development of markets	•Modernizing grid using smart grid technology to increase reliability of electric supply •Launching projects to establish charging and battery swapping stations in different parts of country •Investing in energy storage technologies for EV •Support local EV assembly or manufacturing projects •Initiate informational campaign for electric mobility	•KaV smart metering project is ongoing •Several high-voltage transmission lines are under construction •NEA has initiated project to establish number of charging stations across the country •A Chinese company Talig has started to assemble electric rickshaws and scooters in Kathmandu	GoN (2018b); Ahmad et al. (2020, 2021a)

Table 6 (continued)

Categories	Barriers	Recommended initiatives/solutions	Current status in Nepal	References
Policy and governance barriers	•Political issues •Lack of government's plan and policy to promote EVs •Lack of a policy framework and standard for EVs •Limited incentives for EV users	•Implementing a zero-import/purchase tax policy to encourage consumers to buy EVs •Creating long-term goals and implementing them in stages •Creating technical standards and rules for EVs, such as energy price, taxes, and depreciation •Providing incentives to new entrants in the EV market	•Ministry of Finance and Nepal Rastra Bank (NRB) have increased loan-value ratio for private EVs to 80% in 2017 to encourage adoption of EVs •Import tax of EVs was reduced from 40 to 10% in 2016 for private operators, and for public EVs, it was reduced to 1%	GoN (2018b); Adhikari et al. (2020); Rajper and Albrecht (2020)

effective real-time bi-directional communications, high cost of implementation, and lack of privacy protection (Vaya and Andersson 2012) can pose restraints for its performance in the context of Nepal. But, in a decentralized system, EV users can plan their charging strategy and avoid the issues mentioned earlier to a greater extent (Xu et al. 2019). Both strategies have their pros and cons; however, in decentralized strategy, the quick convergence of optimization problem requires low computational efforts and provides greater efficiency, which indirectly lowers the cost of equipment (Jian et al. 2017; Xu et al. 2019; Liao et al. 2021). So, from cost–benefit perspective, the decentralized strategy appears to be a more feasible system for Nepal, which is in the early phase of EV development. Furthermore, to reap the benefits of the smart charging approach, EV charging stations should be strategically positioned in the distribution network of the power grid following the enhanced approach as discussed in Ahmad et al. (2021b). Nonetheless, before implementation, a detailed study is required to determine whether a particular charging strategy is appropriate for a specific region.

V2X technology

In a smart grid, when linked to the power grid for charging/discharging, EVs are referred to as grid-connected EVs (GEVs). With the plug-in feature, these GEVs can draw energy from the power grid and provide it back to the grid via the bidirectional charger. Depending upon the charging/discharging potential of GEVs and the energy-efficient needs of the power grid, vehicle-to-home (V2H), vehicle-to-vehicle (V2V), and vehicle-to-grid (V2G) concepts (Fig. 13) have grown increasingly appealing. These smart technologies allow GEVs to function as vehicles and flexible, controlled loads and distributed energy sources for the power grid (Liu et al. 2013). Extensive research activities have been conducted to optimize the cost and performance of V2X technology, making it economically and technically feasible (Khan et al. 2018b).

According to NEA, peak electricity demand occurs between 5 p.m. and 11 p.m., and in the same period, most of the vehicles, both public and private, are parked either in homes or stations. In such a scenario, V2H technology allows users to connect several vehicles to an electricity distribution board of home and makes it possible to meet demand at night time. And, the exact vehicle can be changed later from the power grid during off-peak hours or by intermittent renewable sources like rooftop solar PV (Khan et al. 2018a; Shariff et al. 2020). Also, with the advent of V2G technology, EVs may be clustered via aggregator to offer grid services such as load leveling, peak shaving, and voltage regulation at a lower cost and with less environmental effects than present systems. Therefore, with the deployment of smart grid technology, EVs will operate effectively and

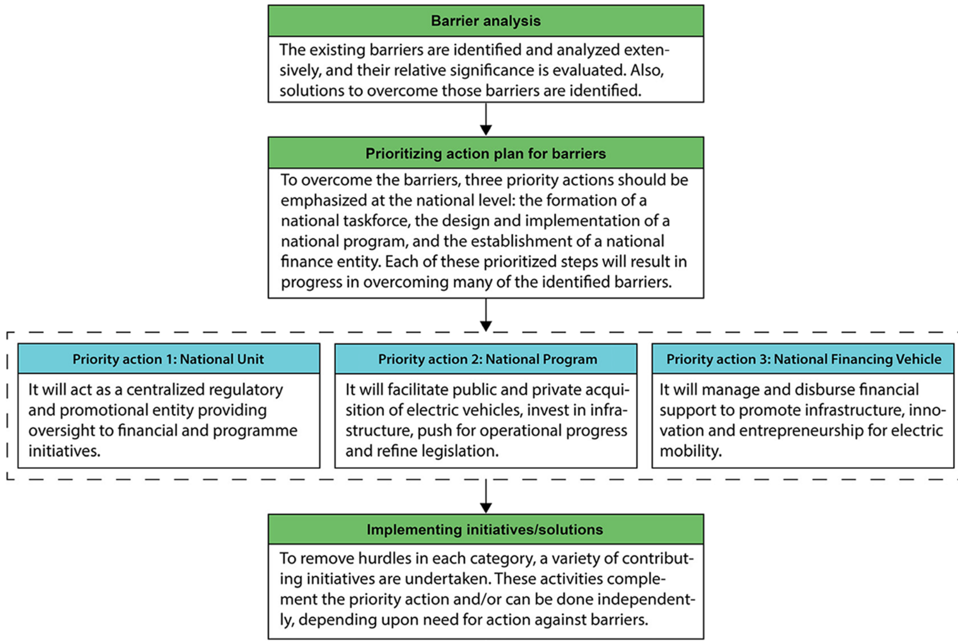


Fig. 12 Policy roadmap/framework for implementing recommended solutions against EVs barriers (GGGI 2018)

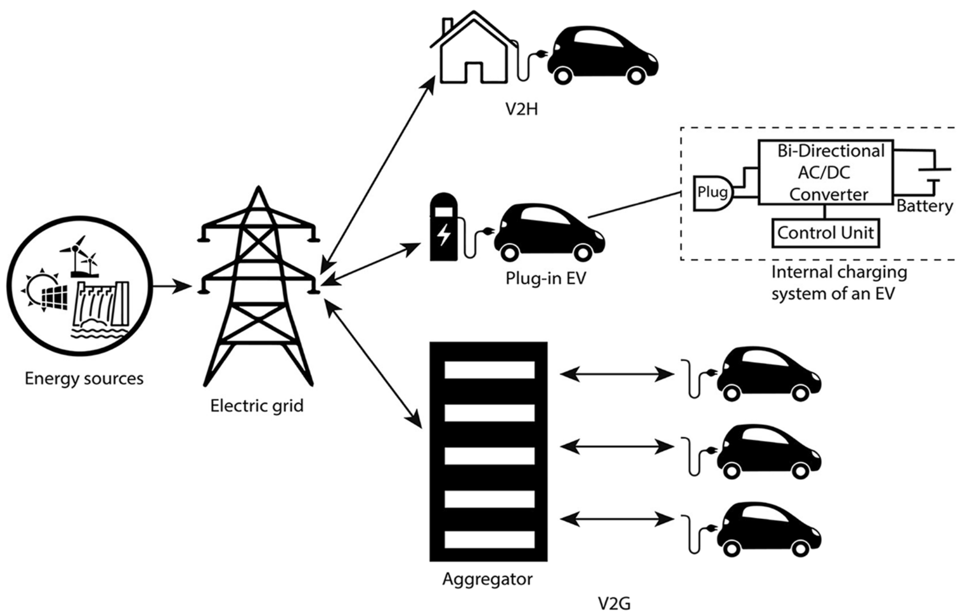


Fig. 13 Electric vehicle concept (V2G and V2H) in a smart grid (modified after Khan et al. 2019a)

in a controlled manner benefiting all the stakeholders associated with it, thus accelerating the growth of EVs in the Nepalese transport industry.

Best practices for deployment of EV charging infrastructure

Energy and charging infrastructure is one of the most crucial components for EV acquisition globally, and utilities are focusing their expertise and resources on infrastructure deployment (Bolduc et al. 2020). According to Adhikari et al., infrastructural obstacles are the most significant impediments to EV adoption in Nepal (Adhikari et al. 2020). Thus, the utility sector of Nepal must adopt best practices to develop a charging infrastructure network that is both effective and efficient. Furthermore, if utilities devote their resources to EV charging infrastructure following best practices, they can produce considerable revenue now or shortly.

EV charging infrastructure should be strategically positioned with careful planning to maximize the usage of existing energy infrastructure while also ensuring that the location is suitable as per the need of users (Hildermeier et al. 2019). To minimize the under-utilization of charging infrastructure, it is vital to determine the density of charging equipment through accurate monitoring of users' charging and driving patterns (Helmus et al. 2018). A report by Smart Electric Power Alliance (SEPA) has discussed the utility-led and third-party EV infrastructure initiative best practices in the US that will aid the utility to develop a successful EV program (Bolduc et al. 2020). While multiple similar options exist for shaping EV charging infrastructure programs in Nepal, their effective execution needs to follow critical steps, as outlined in Table 7. Table 7 also demonstrates best practices shared by successful utilities in the US EV industry; therefore, utilities in Nepal and other developing countries should follow similar practices.

Opportunities for WWTPs in smart grid

Peaking urbanization has adversely affected the water and sanitation sector, resulting in increased wastewater production across Nepal, particularly in highly urbanized and densely inhabited cities like KaV. However, due to poor planning and sluggish development of treatment facilities, it is recognized to have one of the worst wastewater treatment facilities in the Asia–Pacific region (UNESCO 2017). The bulk of existing centralized WWTPs partially function in urban areas like KaV, while rural areas do not have access to them (GoN 2015). One of the main reasons for their poor performance is the inability of the energy system to satisfy their demand (Regmi 2013). Such WWTPs are projected to consume about 30 TWh energy yearly (its breakdown presented in Fig. 14) which may constitute more than 40% of a WWTP's annual operating cost (Lemar and De Fontaine 2017).

For remote areas, decentralized WWTPs like constructed wetlands are considered feasible, cost-effective, environmentally friendly, and sustainable solutions, but constant energy supply is crucial to ensure their practical functionality (Jha and Bajracharya 2014). Since there is an unreliable power

Table 7 Key steps for EVs infrastructure development program with best practices (Bolduc et al. 2020)

Steps	Objectives	Best practices
Planning	To offer a satisfying customer experience, a significant amount of time and effort should be dedicated to the planning phase	Identification of target customers and the number of charging stations required; identification and evaluation of potential sites; determination of customer requirements; establishing quality control process; employee training programs; creating a roadmap for the program; load management strategies; approving charging equipment that meet safety and functional requirements; establishing a process for maintenance of charging infrastructure
Customer engagement	To maximize utility's program budget for marketing and minimize delays	Developing and launching marketing and customer engagement strategies to targeted customers; providing transparency about the program progress; updating customers with change; aware EV manufacturers about the program; coordinating with city leadership and decision-makers; helping communities understand EV technology; being aware of any EV-related incentives and policies by the government
Evaluation	To assess overall feasibility and finalize a detailed implementation plan	Performing high-quality reviews of each potential site before engaging a design firm; standardizing criteria for site design; recommending design based on data (number and type of vehicles, charging time, location, etc.); anticipating customers' plans
Design and construction	To construct charging infrastructure according to plan	Considering a service drop from customer transformer as far as possible; coordinating with authorities having jurisdiction to reduce time and cost linked with the permit and plan checks; engaging closely with final site commencing to ensure all components are installed safely; making provisions for future deployment of additional infrastructures
Customer and regulatory follow-up	To continuously improve utility's program	Surveying customers to determine satisfaction; filing regulatory reports; organizing advisory meetings with stakeholders; publishing results and finding of projects; making aggregated customers charging data freely available; learning to better design and enhance next EV program

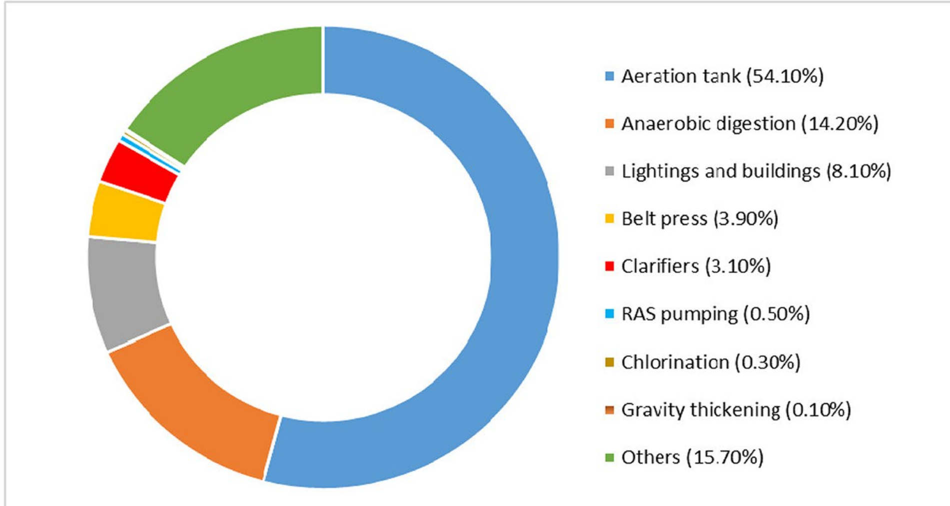


Fig. 14 Energy breakdown of various components of a typical WWTP (data source: Lemar and De Fontaine 2017)

supply in rural areas of Nepal, the reliability of such decentralized WWTPs is questionable.

Making self-sufficient WWTPs by utilizing accessible RESs like biomass, microbial fuel cells, and solar PV is one viable option for maintaining power supply dependability and making WWTPs work efficiently (Quintero Pulido et al. 2018). A net-zero energy wastewater treatment concept (Fig. 15), based on biomass power recycling, was developed to reduce resource waste and enhance energy recycling in wastewater treatment plants (Yan et al. 2017a). This requires an appropriate storage system, appropriate technology for voltage and frequency management, and efficient connectivity to an external power supply. Furthermore, adequate energy forecasting technology is required to anticipate the amount of recovered energy for efficient demand response management inside WWTPs. As a result, smart grid technology has become an essential foundation for building net-zero energy/self-sufficient WWTPs (Moazeni and Khazaei 2021).

Several studies have highlighted the potential of WWTPs to produce biogas, thermal energy, and other biochemical derivatives that can be converted into electricity via a variety of methods, including (a) anaerobic fermentation of separated sludge and conversion of biogas to electricity, (b) combustion of separated sludge and conversion of heat to power, and (c) integration in the water treatment process of microbial fuel cells (Mamut and Badea 2015). Recent research in Nepal found that the entire biogas potential from the projected 200 MLD wastewater in KaV, with an average COD content of 1000 ± 225 mg/L, is estimated to be 23,105 ± 5185 Nm^3/day, corresponding to a total energy potential of 3.35 ± 0.76 MW (Ramtel et al. 2021). With the introduction of smart grid technology, opportunities will

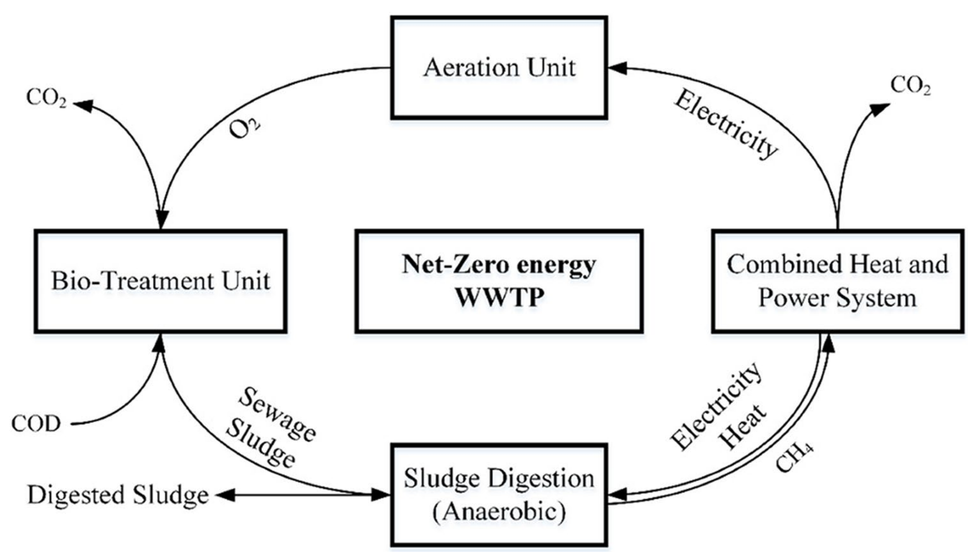


Fig. 15 Net-zero energy concept in WWTPs (adapted from Yan et al. 2017a)

arise to harness the potential bioenergy present in centralized and decentralized WWTPs around the country, allowing them to become energy self-sufficient and excess energy to be incorporated into the national grid line.

Challenges of smart grid implementation in Nepal

Smart grids employ cutting-edge technology to address current complexities in Nepal's traditional electricity networks while also providing a plethora of chances to improve their efficiency and reliability. However, its implementation is hindered by the several technical and socioeconomic challenges summarized in Fig. 16.

Nepal's present grid infrastructure is insufficient to meet expected renewable energy integration and response management demands, posing several smart grid designs, building, operation, and maintenance issues. The frequent and intermittent variation of active power supplied by integrated renewable energy sources causes significant voltage variance at the distribution level. Existing grid voltage regulators, such as tap changers and capacitor tanks, cannot correct rapid fluctuations caused by these sources. As a result, power electronics technologies like FACTS and RACDS, efficient energy storage systems, and other smart technology must be incorporated to ensure voltage and frequency stability in the grid (Fallahzadeh-Abarghouei et al. 2018; Firouzjah et al. 2019). However, smart infrastructures such as smart meters, energy storage systems, FACTS, database management, communication systems, etc. require sizeable initial investment (EPRI 2011). The availability of funding is thus a key barrier to establishing a smart grid in Nepal.

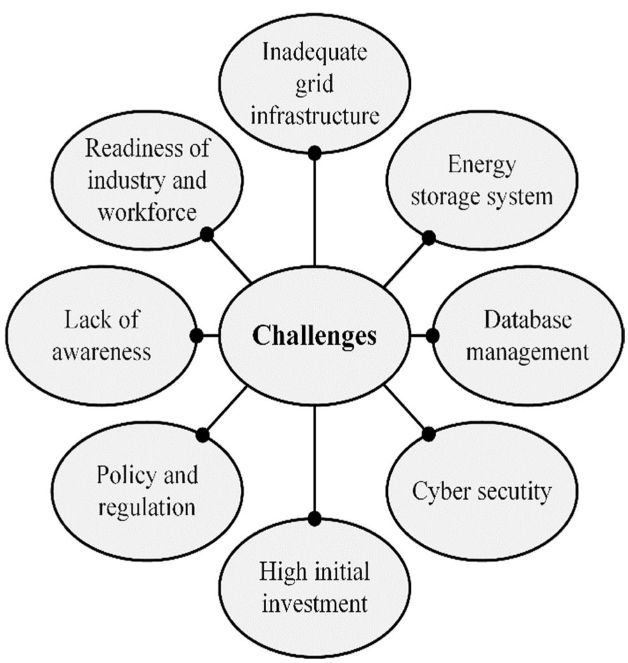


Fig. 16 Major challenges associated with the application of a smart grid in Nepal

In addition, there are no well-defined rules or guidelines in Nepal to govern smart grid efforts. The majority of present legal and regulatory frameworks were created to address existing networks and utilities. As a result, current legislative and regulatory frameworks will need to be amended to facilitate the deployment of smart grids. The new framework must be designed to maximize contributions from all sectors, and all stakeholders—government, utilities/investors, and consumers—share the potential risks. Therefore, new regulations and policies must consider the following aspects (Kappagantu and Daniel 2018):

- Investment to be shared among consumers, utilities/ investors, and the government
- Incentives for the adoption of renewable energy technology
- Reducing the tax levied on EVs and renewable energy technologies
- Create action plans and norms
- Meet all stakeholders' expectations, particularly those of consumers
- A genuine emphasis on workforce development and public awareness campaigns

Utilities in smart grids have a significant data management challenge since a considerable quantity of data is generated. As a result, processing and storing huge volumes of data exchanged among multiple smart grid components need a secure processing and storage facility. Otherwise, hackers and viruses can get unauthorized access to data and leak it, posing a severe threat to users' privacy and confidentiality (Tu et al. 2017). So, database management and cyber security are significant challenges to address while adopting smart grid technologies.

Another obstacle to establishing a smart grid strategy in Nepal can be a lack of consumer understanding about the smart grid. As a result, consumers should be educated about the concept of a smart grid, its role in the transition to carbon-free energy, and its advantages for them. They must also be taught about their energy usage habits, allowing them to participate actively in demand response management and become prosumers (producer + consumer) rather than simply consumers. Furthermore, authorities and regulators must have a comprehensive understanding of the smart grid's future potential, and utilities must concentrate on fully exploiting its capabilities.

Conclusions and policy implications

We reviewed the current scenario, explored the needs, and presented various opportunities that developing countries like Nepal can undertake by implementing smart grid technologies. Through these technologies, Nepal can increase the share of renewable energy usage to address current and future energy problems and contribute toward the global sustainable development goal.

The semiconductor-based FACTS and RACDS devices, by replacing current mechanically-driven devices, will make the system more responsive during faults, and energy losses will be reduced. Similarly, a smart grid will provide a huge opportunity to alleviate the rural electrification problem by widely implementing smart microgrids built on plentiful RESs such as solar PV, wind, and biomass, engaging the private business and connecting them to the national grid. Similarly, smart and scheduled charging of EVs in a smart grid environment will encourage people to embrace EV technology; therefore, vehicular emissions and dependence on fossil fuel will be reduced significantly. EV concepts such as V2H and V2G will enable EVs to be utilized as both an energy supplier and a load, making them essential partakers in demand response management. Furthermore, by capturing, regulating, and controlling their potential biomass energy, the smart grid will assist WWTPs throughout the country to become energy self-sufficient.

Although smart grids provide a broad range of opportunities for power sector reform in Nepal, several technical and socio-economic challenges may make their implementation difficult. These issues can be addressed if the GoN and NEA jointly adopt policies and strategies that promote their development. The results of existing smart grid initiatives like the Kathmandu Valley Smart Metering Project, on the other hand, can offer insight into how its development will proceed in Nepal.

The findings of this study imply that several components of smart grid technology are in a trend of progressive deployment in the country as a result of new initiatives, policies, and frameworks implemented by the government and related authorities in recent years. Also, this paper concludes that there is a significant potential of this technology in Nepal's energy sector for the effective and efficient utilization of vast RESs, better energy management, environmental protection, and overall socio-economic progress; however, there is a significant gap between current degree of achievements and the potential available. The following policy-related suggestions are proposed based on the findings of this study. First, government and other national authorities should make policies and frameworks that support and prioritize the investment in RETs. In this regard, a stable political environment is necessary to assure the safety of investment of domestic and foreign investors. Also, the government should proactively promote the research and development activities to identify the issues concerning the time and budget overrun of national-level hydropower projects to avoid similar complications in the future. These policies should be designed optimally to reinforce the other climate change–related policies. Second, utilities should pursue digitalization, which provides a significant opportunity to minimize grid losses, energy theft, timely fault detection, and operational expenses. Digital media makes it easier for customers to analyze and manage their energy usage patterns, reduce energy waste, and support demand-side management. Third, the increasing necessity for grid restructuring demands decentralized the power system control. Currently, NEA is the centralized government entity that monitors the planning, execution, and operations of projects and initiatives related to different components of the power system. With a large number of distributed RESs generating energy in near future, it will be difficult to manage centrally. Therefore, for Nepal's energy sector seeking resiliency, reliability, and flexibility, a decentralized control system might be a new paradigm.

In essence, policymakers in developing countries like Nepal should promote the smart grid approach to minimize energy loss, lower energy costs, utilize clean energy, and improve power system reliability and management. This will also result in new employment opportunities, which will help the country's overall socio-economic growth. In a broader sense, the advent of smart grid technologies will not only serve as a solution to existing energy-related problems across developing countries but will also reduce global carbon footprint and contribute to the achievement of global sustainable energy goals, and thus lessen the impacts of global climate change in the years to come.

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