

Review

A Review of the Integrated Renewable Energy Systems for Sustainable Urban Mobility

Hanadi Al-Thani *, Muammer Koç , Rima J. Isaifan  and Yusuf Bicer 

Division of Sustainable Development, College of Science and Engineering, Hamad Bin Khalifa University, Qatar Foundation, Doha P.O. Box 5825, Qatar

* Correspondence: hgalthani@qf.org.qa

Abstract: Several challenges have emerged due to the increasing deterioration of urban mobility and its severe impacts on the environment and human health. Primary dependence on internal combustion engines that use petrol or diesel has led to poor air quality, time losses, noise, traffic jams, and further environmental pollution. Hence, the transitions to using rail and or seaway-based public transportation, cleaner fuels, and electric vehicles are some of the ultimate goals of urban and national decision-makers. However, battery, natural gas, hybrid, and fuel cell vehicles require charging stations to be readily available with a sustainable energy supply within urban regions in different residential and business neighborhoods. This study aims to provide an updated and critical review of the concept and recent examples of urban mobility and transportation modes. It also highlights the adverse impacts of several air pollutants emitted from internal combustion engine vehicles. It also aims to shed light on several possible systems that integrate the electric vehicle stations with renewable energy sources. It was found that using certain components within the integrated system and connecting the charging stations with a grid can possibly provide an uninterrupted power supply to electric vehicles, leading to less pollution, which would encourage users to use more clean vehicles. In addition, the environmental impact assessments, as well as several implementation challenges, are discussed. To this end, the main implementation issues related to consumer incentives, infrastructure, and recommendations are also reported.

Keywords: alternative fuels; clean transportation; electric vehicles; green vehicles; hydrogen; renewable energy; sustainable cities



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1. Introduction

The overall greenhouse gas emissions and other gaseous and particulate emissions in urban environments have been adversely impacted by fuel consumption in the transport sector [1]. Hence, to achieve several environmental sustainability goals, electricity production from renewable resources and electrification in the transport sector should be promoted [2]. It has been reported by the International Energy Agency (IEA) that transport emissions make up around 25% of the total global energy consumption. Moreover, these emissions increased by 0.5% in 2020 compared with 2019 [3]. However, due to the instability in electricity production from renewable energy resources, energy systems should have reserves in conventional energy storage devices. This target might be achieved by the use of electric vehicles (EVs) since they provide improved battery charging capacity when they are connected to a grid [4,5].

In this review, the research published in different databases, such as Google Scholar, Science Direct, Scopus, and Springer, was obtained based on certain keywords. The keywords used for screening the available resources were ammonia, natural gas vehicles, green vehicles, renewable energy, electric vehicles, on-grid, green vehicles, sustainability, urban mobility, economic feasibility, and transport pollution [6].

Several reviews have reported on aspects related to integrating green vehicles into the energy system. Costa et al. reviewed several urban mobility indexes and recommended that a greater number of investments be devoted toward regional infrastructure and developing policies to improve urban mobility [7]. Gallo et al. conducted a preliminary analysis of the sustainable mobility concept with a focus on the main policies in the USA and the EU. They also examined sustainable mobility from environmental, socio-economic, and technological points of view [8]. Enang et al. provided an extensive technical review on the modeling and controlling of hybrid electric vehicles (HEV). The authors highlighted that the main challenge in developing an HEV control strategy lies in the satisfaction of often-conflicting control constraints involving fuel consumption, emissions, and drivability, without over-depleting the battery state of charge at the end of the defined driving cycle [9]. Igbinovai et al. reviewed some proven innovative charging techniques by different authors utilizing diverse tools for the electric vehicle [10]. Mahroogi et al. reported on a recent review of hybrid automotive systems in the Gulf Cooperation Council (GCC). The authors noted that although the market for hybrid vehicles is growing globally, it is still in the developing phase in the GCC. They recommended that awareness be spread about the environment and that costs associated with using HEV be lowered. More specifically, the greenhouse gas emissions savings were found to be 9–13%, while fuel savings per 100 km were in the range of 8–10 L [11]. Moreover, Sorlei et al. compared the latest proposed technologies for fuel cell electric vehicles and analyzed (using software) several energy management strategies that are considered the main challenges for developers [12].

Some of the performance indicators of fuel cell vehicles that were analyzed are energy efficiency, hydrogen consumption, and degradation of the subsystems involved [12]. Goel et al. conducted an overview of the penetration rate of electric, hybrid, and plug-in hybrid electric vehicles into the Indian market. The authors found that reducing emissions and dependency on fossil fuels has promoted large-scale renewable deployment. However, several challenges were highlighted, such as the presence of essential barriers and insufficient charging facilities in India [13]. In China, Hao et al. noted in their recent review that there had been remarkable progress in promoting natural gas (NG) vehicles with the largest NG vehicle fleet in the world [14]. The authors presented the development of this vehicle from a triple perspective that is based on infrastructure, as well as technical and economic frameworks. The review has further discussed the pricing policy and the essential role it plays in determining NG vehicle development. To this end, the review recommended that local governments should launch dedicated plans and strategies to support the further deployment of CNG/LNG refueling infrastructures [14]. Waseem et al. recently reviewed the integration of electric and hybrid vehicles with charging stations powered by solar energy. The authors discussed the major barriers and challenges to adopting PV technology in electric and autonomous vehicles [15]. Mohammad et al. reviewed the state-of-the-art literature on modeling grid-connected EV–PV (photovoltaics) systems. Further, the authors evaluated the uncertainty modeling methods associated with various parameters related to the grid-connected EV–PV system and provided potential research directions in this area [16].

Table 1 identifies the main areas that have been reviewed in the field of sustainable urban mobility. The main contribution of this work is in conducting a comprehensive review to discuss a wide range of green vehicles and their integration with renewable energy resources. It discusses the concept of sustainable mobility and transportation modes within urban contexts. Most reviews published earlier discussed the integration with solar panels, but not with the wind [15,16]. Moreover, the main challenges related to implementing sustainable urban mobility with 100% renewables are discussed from a global perspective and not in a fixed domain related to a specific country or region.

Table 1. Summary of published reviews on sustainable mobility. BEV: Battery electric vehicles, FCV: Fuel cell vehicles, NG: Natural gas.

[illegible]

The findings in this review highlight the adverse impacts of several air pollutants that are emitted from conventional vehicles that use fossil fuels. It also highlights green vehicles' main aspects, components, advantages, and disadvantages. These include batteries, natural gas, fuel cell, and hybrid vehicles. Several cases reporting on the integration of green vehicles with renewable energy sources are included. Moreover, the environmental impact assessments and several implementation challenges are discussed. To this end, the main implementation issues related to consumer incentives, infrastructure, and recommendations are provided.

2. Urban Mobility and Transportation Modes

As the population globally increases, there is a growing challenge to adapt proper urban development plans to meet the needs of efficient urban mobility [7]. Mobility is the ability to move from one place to another [17]. Magagnin et al. defined mobility as a quality that determines urban space for several purposes, including the ability to go to work or school, run daily errands, attend leisure activities, etc. [18]. Certain factors play a role in an area's urban mobility, such as gender, the area's average income, age range, the preferred mode of transport, and many others [17].

It has been reported that the recent deterioration of mobility and the evolution of several environmental and human-related health problems were associated with the careless and relatively fast-paced development in heavily populated areas [1,19]. The continuous delay in considering proper planning of the transportation systems in several regions worldwide has contributed to an increase in adverse impact on living conditions in those areas. Therefore, there is a pressing need to seek methods and processes to protect the environment and provide sustainable mobility and transport within the urban areas. Such strategies should be of high quality and serve urban areas' future development, including transport infrastructure and other mobility services, for a long time [7].

However, sustainable urban mobility plans aim to improve accessibility in central locations within urban areas to comply with society's needs: people should be able to communicate, move comfortably, and form relationships freely. This can only be done when the time needed to complete daily tasks, such as going to work or attending school, is practicable and does not create a hindrance for the individual. Values should not be compromised for task execution time, whether it is related to leisure or one's work [7,20].

Growing traffic jams in urban areas due to the excessive use of individual vehicles have damaged the environment and human health. Hence, it is of paramount importance that alternative options for urban mobility modes shall be introduced, such as the use of public transportation of quality and fair prices [7]. Hence, enhancing sustainable mobility is one of the main goals of transport policy [8]. The term "sustainable mobility" was coined, meaning "to ensure that our transport systems meet society's economic, social, and environmental needs while minimizing their undesirable impacts on the economy, society, and the environment" [21]. It is important to note that the research conducted on this matter no longer focuses solely on the environmental aspects of the issue, albeit its crucial significance. Sustainable mobility cannot be looked at as a matter that can be solved merely by using less harmful and contaminating transporting systems, even if it is a good start. Economic and social impacts must be considered at all levels.

On a broader scope, sustainable mobility typically encounters all modes of urban transportation: road, sea, air, and rail, since they all contribute to environmental pollution and noise issues [22,23]. Several laws have passed to penalize exceeding the traffic noise limit. The Environmental Protection Agency (EPA) has enlisted penalties for using vehicles that exceed the prescribed noise limit. The fines ranged from USD 150 for a 5 dB increase above the traffic noise limit to USD 1200 for a 15 dB increase above the traffic noise limit. Moreover, in New York City, for instance, the fine ranges from USD 250 to USD 1000 for the first, up to the fourth violation, at an incremental increase of USD 250.

Several precaution measures have been suggested to minimize the impact of traffic noise if limits are exceeded, such as avoiding residential areas being built near busy roads.

In cases in which homes were built on the premises of heavy traffic, home insulation and noise barriers should be implemented at an early stage of construction.

However, this review paper focuses on integrating renewable energy sources with the charging stations of green road vehicles as they make up most of the urban mobility system.

3. The Impact of Urban Transport Emissions on Human Health

Several studies have reported on the impact of road traffic emissions in urban areas [1,15,16]. The impacts of these emissions were studied in terms of their effects on materials, welfare, and adults' as well as children's health [24–27].

3.1. Nitrogen Oxides (NO_x)

Nitrogen oxides' health impacts have been associated with asthmatics symptoms and reduced lung growth in children [28]. However, the link between elevated NO_x levels with these diseases has not been assessed as strong enough compared to the threat of other contaminants [29]. Recently, Al-Ahmadi and Al-Zahrani examined whether the occurrence of most common cancers in Saudi Arabia was linked with NO_2 urban air pollution exposure. Essentially, a high correlation was observed in and around the cities of Riyadh and Mecca. The coefficients of determination between specifically lung cancer and NO_2 concentration levels were significantly high, followed by other types of cancer, such as bladder, ovarian, cervical, and even prostate [30]. The results can be further analyzed when taking other variables into account, such as socioeconomic, genetic risk, demographic, and environmental factors [30].

3.2. Sulfur Dioxides (SO_2)

Sulfur dioxide is a primary pollutant and generates secondary pollutants that induce adverse health effects. SO_2 is known to be highly linked to cardio-pulmonary (heart and lung) illnesses as well as mortality. This can lead to asthma, constrained activity, frequent sick leave, and hospitalization [29]. Several studies in the Public Health and Air Pollution in Asia (PAPA) project investigated the correlation between ambient SO_2 and daily mortality in Far East urban cities. The approximations of the effects on health were acquired separately and collectively for each city. The significance of the SO_2 on cardiopulmonary mortality was detected in both the separate and collective results [31].

3.3. Particulate Matter (PM)

Particulate matter is normally classified as $\text{PM}_{2.5}$ and PM_{10} . $\text{PM}_{2.5}$ refers to particulates of diameter equal to or less than $2.5\ \mu\text{m}$ which are considered fine. Coarse particles have a diameter equal to or less than $10\ \mu\text{m}$ [24]. A larger particulate is usually the culprit in causing respiratory and lung disease. Smaller units or particulars, on the other hand, are responsible for cardiovascular or heart-related complications [25]. This is because particles larger than $10\ \mu\text{m}$ are removed in the upper airways, contrary to the fine particles that penetrate the body and reach into the bloodstream. It was reported that fine particulates are emitted from combustion processes, while the physical wear of roads and tires produce coarse particles [32].

It was reported that excessive exposure to ambient particulate matter is a key risk factor for illness and mortality [33]. Generally, it is linked to cardio-pulmonary complications, such as heart disease, lung cancer, stroke, and asthma. It is also believed to be associated with dementia and loss of cognitive function [27–29,34]. Heavy road traffic is a commonly known factor of air pollution but recent studies have also indicated that underground railways are just as polluting to the environment and are yet another culprit [35]. There is still much to be discovered about the consequences of particulate matter and the sources from which it arises. Understandably, there is very poor air ventilation in underground railways, hence the PM levels. Millions of people worldwide use underground railways daily, making them susceptible to it. Recently, Loxham et al. reported on 27 publications specifically investigating the possible health impacts of PM found underground [35]. The results of these studies were examined in-depth and then reexamined and analyzed using

other literature on the individual results. In vitro studies that they conducted revealed that underground PM can be more toxic than exposure to ambient PM since it contains toxic metal compounds [35]. Moreover, daily NO_2 and NO_x were linked to higher risk of hemorrhagic stroke for a large cohort of post-menopausal US women [36].

Particles of vehicle exhaust are typically considered fine $\text{PM}_{2.5}$ due to fuel combustion. As mentioned earlier, $\text{PM}_{2.5}$ has been reported to cause acute and chronic illnesses and mortality [31,32]. The diseases associated with these health impacts can be cardiovascular and respiratory [37]. Due to their concentration and size, the smallest particles, or nanoparticles ($<0.1 \mu\text{m}$), appear to be highly toxic. This is because their total surface area can be very large even though they are small in mass. When the particles are inhaled, it is primarily the surface area that reacts with the cells, hence the critical aspect of surface area concerning toxicity [29].

3.4. Wear Particles

Brake and tire wear in addition to road dust resuspension are considered the main sources of transport-emitted coarse particles [1]. The levels of wear particles are seasonal and vary throughout the year. The arrival of the winter and spring seasons brings about the use of studded tires, and long hours of salting and shoveling the streets allows for high concentration levels of wear particles [29]. Due to their crudeness, wear particles are considered coarse $\text{PM}_{10-2.5}$. [29]. A recent study conducted on diesel vehicle emissions in Qatar reported that the enrichment factor of anthropogenic elements in road dust amounted to 350. It was reported that the traffic source based on sulfur elemental fingerprint was almost five times greater on main roads than the samples collected and analyzed from non-traffic residential locations. The primary source of the element was the tire wear with 33%, followed by dust resuspension (31%), and brake wear (19%). The exhaust emissions were much lower at 17%. The lower contribution of exhaust compared to wearing particles was due to the fact that the vehicles reported were relatively new, meaning they were built with exhaust-reducing technologies [1]. Several countries have taken the initiative to ban the use of studded tires, but regulations to control non-exhaust emissions are nearly absent. Therefore, while technology is constantly evolving to decrease exhaust emissions and exhaust-related sources, there is a huge lack of advancement and effort regarding non-exhaust-related emissions. This problem can be tackled if sufficient research is produced on non-exhaust particles and their severe impacts on health and wellness [1].

3.5. Diesel Particles

Diesel particles are usually interrelated with other poisonous pollutants [29]. However, more measures should be considered regarding PM exhaust emissions. Older cars still release very harmful levels of PM, and one way to tackle this issue is the implementation of filters as a mandatory addition before vehicle registration renewals. Three approved technologies can be added to diesel engines, the first being partial flow filters (PFF) with a PM reduction potential of 30–60%. The second is wall flow filters (WFF) which have a potential of $>95\%$, and finally, diesel oxidant catalyst filters (DOCF) with a potential of $<25\%$ [34,35]. In order to control these emissions, in Europe, low and ultra-low emission zones are being continuously practiced [38].

3.6. Carbon Monoxide (CO)

The consequences of long-term exposure to carbon monoxide are well known due to the antagonism of carbon monoxide with oxygen when they compete for binding sites on hemoglobin, which causes reduced oxygen transport [39]. Although the method underlying the neurological damage is not adequately understood, it is assumed that CO causes an inflammatory response that may be initiated during the recovery phase when the blood with increasing levels of oxygen reaches the tissues that had been hypoxic [39]. It is known, however, that short-lived exposure or contact with high levels of carbon monoxide results in changes in cognitive abilities. Carbon oxide is thought to be especially harmful to people over 65, causing specifically cardiovascular health issues [19]. That being said, CO's contribution is relatively small compared to the entire health cost of traffic emissions [29].

3.7. Carbon Dioxide (CO₂)

Carbon dioxide emissions are among the main concerns due to the increased urban transport usage. It was reported that 60% of the population in the European Union lives in urban areas. The cars reported in urban areas run about 75% of their mileage in and around the cities. The continuous increase in traffic has led to permanent congestion in those areas. In addition, this has exposed the citizens to high levels of air pollution, including elevated levels of CO₂, NO_x, PM₁₀, and SO_x [12]. Moreover, in the US for example, 31% of total CO₂ emissions are caused by burning diesel and gasoline for transportation. This alone contributes to about 26% of total greenhouse gas emissions in the country, according to the USEPA in 2013. This phenomenon contributes to the wider impact related to climate change. Consequently, policymakers in transport sectors are urged to mitigate and alleviate the adverse impact on the local and global environments [40]. Recently, the EU has reported that they aim to reduce greenhouse gas emissions by 20% with respect to 1990 [41].

3.8. Metals

Several metals have been linked with cancer, such as Ni, As, Cd, and Pb [29,42,43]. Several cardiovascular diseases have been linked with a high level of Benzene, As, Cd, and Cr. However, lead has been proven to cause several neurological health impacts and has been banned in several countries around the world [29].

Health-related impacts of road emissions are significant but are rarely coherently included in transport projects' economic evaluations. It was reported that traffic pollution exposure is a leading cause of cancer and chronic cardiovascular diseases [44]. Moreover, the estimated health and non-health-related automobile costs implied that the reliance on vehicle use induces several health impacts. For instance, sedentary lifestyles due to less walking than riding in a vehicle, air pollution due to vehicle emissions, and traffic accidents all impact human health. However, several impacts that are not related to health are also shown, such as costs associated with vehicle ownership, insurance, parking, and other services. The results motivate the public and decision-makers to adopt electric and green vehicles to reduce the adverse impact of polluting vehicles in urban areas [44].

The EPA has proposed several precautionary measures related to particulate and gaseous traffic emissions. The main recommendation is to avoid exposure to such pollution, which implies avoiding walking or doing sport near traffic. When particulate emissions are at critical concentration, it is recommended to use face masks to prevent them from penetrating the respiratory system. However, several steps to mitigate traffic emissions have been suggested, which mainly implies less and wise driving, using fuel-efficient vehicles, promoting the use of electric and clean vehicles, and optimizing home deliveries.

As deaths due to traffic pollution-related health conditions rise, several steps have been taken by the government, non-government (private) sectors, as well as the public to alleviate these risks. Table 2 shows a summary of the main actions taken by each party.

Table 2. Involvement of government, private and public sectors to alleviate health impact of traffic pollution.

Strategy	Involved Sector		
	Government	Private	Public
Raising awareness on the health impact of traffic pollution	x	x	x
Reducing congestion and roadway expansion	x		
Use of alternative clean fuels			x
Less and wise driving			x
Increasing fuel tax and emission fees	x		
Improving cycling & walking tracks and conditions	x		
Implementing annual checks programs for lung cancer screening	x	x	x
Making public transport affordable or free	x		

4. Overview of Green Vehicles

The following sections highlight the main features of clean vehicles [45] (i.e., battery-, fuel cell-, hybrid-, and natural gas-powered).

4.1. Battery Vehicle

Electric vehicles (EVs) move using an electric motor instead of using an internal combustion engine (ICE) [8]. Electric vehicles require a charging port and outlet to charge their batteries fully. Another name for them is Battery Electric Vehicles (BEVs). In other vehicles, such as conventional hybrids (HEVs) for example, the engine requires both fuel and electricity to run. This is done to limit the combustion process but does not eliminate it. It is the same with plug-in hybrid electric vehicles (PHEVs). Drivers do not usually prefer EV technology as it is considered less reliable regarding range. This is called “range anxiety” [46].

New technologies and numerous literature were introduced to tackle this issue, such as new battery technologies and upgraded power systems [47]. For instance, recently, the regenerative braking system (RBS) is considered one of the battery-saving technologies [46–48]. Another proposed solution relies mainly on station-based battery swapping to provide charged batteries in much less time than usually required, hence providing the optimal conditions for energy usage [49]. Additionally, battery vehicles are considered to have a limited charging structure. They typically cannot have enough battery capacity for longer drives. One way to tackle this issue is to improve the distribution of charging stations throughout urban areas. If this does occur, there would be an increase in demand for this technology, which would lower the range anxiety levels. However, with more demand, more technology is required. Grid load management would be essential as the demand for electric vehicles rises [50]. Smart grid technologies have been designed to tackle this issue of the increasing need for energy [51]. vehicle-to-grid (V2G) technology is an example of these technologies. Through this, the energy that is gathered in the battery is redistributed into a grid which reduces the amount of energy required from the main source. Optimization should be considered with the usage of grids to ensure that the energy distribution is as efficient as possible. Finally, inductive charging systems have recently been introduced. This is considered a recent technology and allows for roads to be electrified for the purpose of charging vehicles while driving. Hence, to attain the objectives mentioned above, an intense effort was devoted to developing new fuels and engines that are capable of reducing or minimizing pollutant emissions from the transport sector [8].

4.1.1. Electric Vehicle Market Outlook

The electric vehicle market is expected to grow further in the coming decade and it is estimated that 50% of vehicles driven in 2040 shall be EV [52].

It was reported that the high number of EV and plug-in hybrid EV vehicles sold in China is proportional to the population relative to other regions worldwide. Moreover, the surge in sales and production reflects Beijing’s push to have new-energy vehicles make up a certain share of production and sales. What encouraged the production and sales further is the extended subsidies by the Chinese government for two years, which had previously been set to expire at the end of 2020.

4.1.2. Cost of Electric Vehicles

Electric vehicles are more expensive than internal combustion engine vehicles (ICEV) in terms of capital expenditure due to the high cost of lithium batteries [53]. On the other hand, electric vehicles have lower operational costs compared with internal combustion costs (ICEVs). The total cost of ownership demonstrates the cost efficiency of EVs in comparison to ICEVs. In addition, the Total Cost of Ownership (TCO), which relates to maintenance and insurance affects the average lifetime costs of vehicles. It also varies from place to place due to differences in fuel costs and import tariffs [52].

4.1.3. The Climate Performance of EVs

The dependence on EV transportation is expected to combat climate change if utilized in energy systems that incorporate renewable energy sources. For instance, CO₂ emissions can be offset if EV was used in an economy with a high share of coal in the electricity generation mix. It was reported that EVs operating mainly on renewable energy systems have a great potential to reduce CO₂ emissions. Moreover, the higher emissions of EV manufacturing due to the EV production can be offset if the latter depends on renewable energy that makes up 45–50% of the electricity mix [52]. However, it has to be noted that if the grid-mix is mainly dependent on fossil fuels, the emission reduction potential of EVs is very low.

4.2. Hybrid Vehicles

The main components of a hybrid vehicle are the engine, battery, and motor. The battery can be a fuel cell and supercapacitor to store energy. Hybrid vehicles can be classified according to the arrangement of drive trains [9]. Therefore, in a series arrangement, the engine, driven by a battery operating at a constant speed, is what gives the motor its power to drive the vehicle (Figure 1).

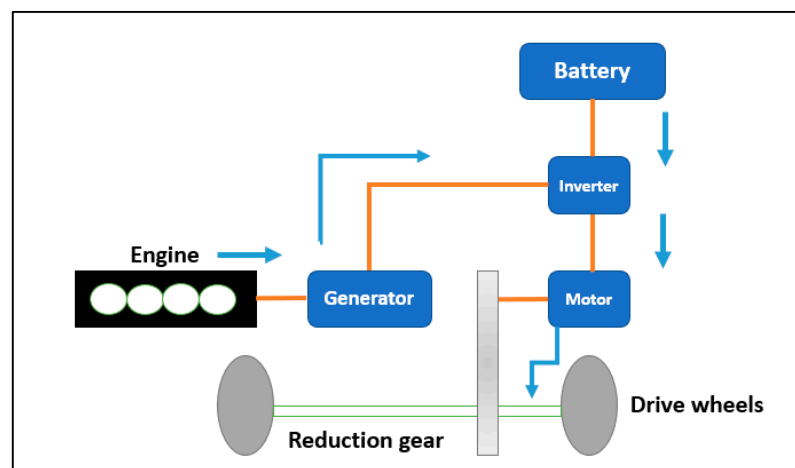


Figure 1. The series arrangement, reproduced from [11].

However, if both engine and motor are connected to the transmission system, it is considered a parallel arrangement, as shown in Figure 2. The last compartment is the motor, where the permanent magnet and induction motors are widely used.

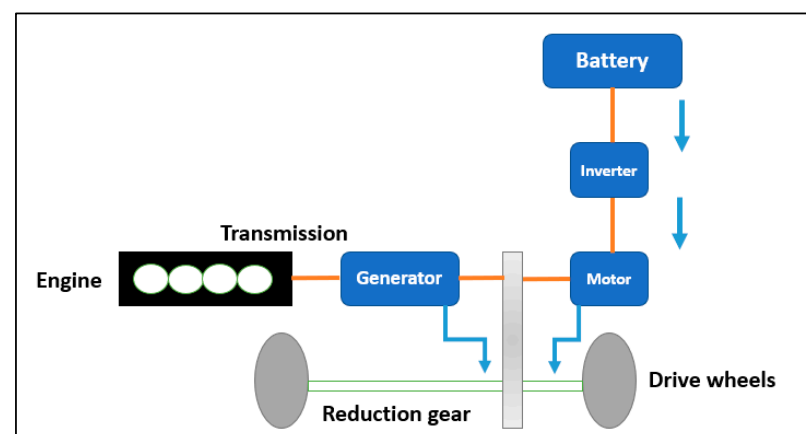


Figure 2. The parallel arrangement in HEV, adopted from [11].

It is worth noting that there are several kinds of hybrid vehicle technologies, such as mild HEV, micro HEV, full HEV, and plug-in HEVs. Full HEVs are classified with smaller engines and need more complex electric motor (EM) systems. Plug-in HEVs need their own separate external plug for charging. Their electrical components are larger and hold more capacity, and they have smaller engines, making them able to operate on the electric power for an extended period.

Fuel cells have higher energy density values, making them suitable as motor energy suppliers for operating hybrid vehicles. Water is the only by-product of the technology if hydrogen is used as fuel. However, they require auxiliary sources, such as lead–acid, Li-ion, and Ni–MH battery types. The various advantages of HEVs include no fuel consumption or combustion, downsizing, the regeneration of kinetic braking energy, and the removal of the starter motor [11].

4.2.1. Hybrid Vehicles and Greenhouse Gas Emissions

Several studies have reported on the energy management strategies for hybrid vehicles [54,55]. At lower speeds, maximum torque is produced in HEV engines, making the use of the motor more dominant. This means that whenever the vehicle is at a lower speed, it is automatically on only electric power. The reliance on the motor decreases as the speed of the vehicle increases. Several approaches to energy management for HEVs can be split into two fundamental approaches. One is related to global optimal control methods, and the other is related to instantaneous control methods. About a 30% decrease in the total fuel consumption was reported for HEV compared to conventional vehicles. However, spatial variations were noted due to vehicle maintenance costs, differences in fuel prices, national and international policies, and insurance [11].

4.3. Fuel Cell Vehicles

4.3.1. Components of Fuel Cell Vehicles

It was reported that the EV market has risen recently. However, to secure a sustainable and electric-power distribution grid, smart charging techniques should be implemented [10]. The fuel cell vehicle's main components mainly depend on a fuel cell stack to generate electricity from hydrogen, a battery to store the energy, a hydrogen tank to store the hydrogen fuel under high pressure, a power control unit to manage the fuel cell stack, and a battery and motor to run the electricity from the fuel cell and the battery [10].

4.3.2. Fuel Cell Vehicles Operation

Hydrogen fuel cells (HFCs) generate electricity from hydrogen that undergoes a chemical reaction in a fuel cell and provides it to an electric motor [8]. The hybridization of the battery has led to the development of HFC vehicle (HFCV) technology. These are preferred due to their single electric motor because traditional hybrids usually require more than one motor to operate [8]. A comparison of plug-in hydrogen fuel cell hybrid vehicles with BEVs showed that they share the same level of life cycle costs but with better advantages that can be achieved from efficient driving patterns [56]. The research conducted in this field focuses on exploring optimal energy and power generation systems. The latter can be attained when fuel cells are combined with super capacitors [57]. To develop the functioning, durability, and performance of the storage system, energy management is used to discover and reach the optimal balance between the varying sources, as reported by [58].

The widespread use of electric vehicles (EVs) depends heavily on the distribution of charging stations. When EV charging stations are available and accessible, it is much more likely that the public is comfortable choosing electric vehicles. One option is using hydrogen and ammonia fuel cells. Doing this will allow the two chemicals to stay as such when there is a production surplus. Because ammonia can be stored as a liquid, the capacity for storage needed is much less than if it was stored as a gas. This also reduces the potential losses. The designed system can generate about 80% of the charging station. However,

several factors, such as solar irradiance, wind speed, and fuel supply rates, play key roles in the overall system's efficiency [59].

Bicer has suggested several design requirements to be integrated into the design of the smart city area for optimal functional energy performance and conversion steps [59]. Those system design requirements are related to the local H₂ production, solar electricity availability, fuel cell electric vehicle-to-grid operations, smart grid control, and building electricity consumption. They include hydrogen tube trailer transportation, hydrogen fueling stations, road transportation via large-scale and shared wind hydrogen production, and large-scale and shared seasonal hydrogen storage.

Similar challenges were reported for integrating fuel cell vehicles with electric power systems in urban areas in terms of meeting the power supply from the grid [60]. However, more specific challenges were reported related to fuel cell vehicles. A particular operating procedure should be considered for these FCVs [12]. Another challenge was related to the plug-in FCV which is widely used but has shown low flexibility in controlling the power flow, consequently affecting the need allocation within the infrastructure for sustainable flow and operation [61]. Moreover, Tran et al. reported that since most power and energy management strategies methods are currently based on prediction algorithms or predefined rules, they have the disadvantage of poor adaptability to real-time driving conditions and do not offer real-optimal solutions [55]. This would, in return, affect the prediction of demand when designing the infrastructure for such integration. It is also reported that the challenges and barriers are more pronounced in developing countries due to insufficient charging facilities. The development of the new concept of vehicle-to-grid systems has created an extra power source and need when renewable energy sources are not available or not sufficient [13].

4.4. Natural Gas Vehicles

In addition to the challenges that have been reported above, the main infrastructure challenge for natural gas vehicles' integration with the urban transport system is ultimately the availability of a dedicated refueling infrastructure, which can be costly [14]. In addition, even if the refueling infrastructure was approved financially, it should be compatible with the existing refueling infrastructure [14]. Moreover, despite the fluctuation in natural gas prices and the history of losses due to the 2013–2014 price impact, several companies continued to operate based on their strategic objectives despite the losses they faced [14].

5. Integration of Green Vehicles Charging Stations with Renewable Energy Sources

Green vehicle charging stations can be built off-grid and on-grid. On-grid electric vehicle charging stations are more favorable due to their efficiency and continuity in terms of energy supply. On the other hand, off-grid charging stations have been recommended for remote locations to encourage and increase the use of electric vehicles [62]. Off-grid clean charging stations mainly depend on renewable energy resources to generate electricity. An efficient off-grid charging station should consist of three subsystems: PV generation, electric vehicle charger, and energy storage system. However, the most common charging systems are on-grid to assure continuity and a sustainable flow of energy, as will be discussed in the following sections. Solar and wind renewable energy sources can be integrated with EVs to generate electricity, as shall be discussed in the following sections. Moreover, hydrogen and ammonia energy carriers shall be also discussed.

Although long-term environmental and economic benefits are associated with the integration of renewable energy into the transportation system, several challenges related to land spaces, infrastructure preparation, capital cost, and reliability associated with these integrations shall be presented.

5.1. Integration with Solar Energy

Electricity can be obtained from solar energy, which is available without cost in several regions around the world using PV technology [15]. Many studies related to the EVs'

charging application have shown that electrical and hybrid vehicles can be used via PV technologies through two different modes [63]. The first involves directly integrating PV panels with the electric and hybrid vehicles, while the second mode incorporates the installation of solar PV stations to recharge them. However, the authors reported on several limitations based on the implementation of solar power-assisted electric vehicles, which are all related to the non-uniformity of solar irradiance, leading to range anxiety issues [15]. The CO₂ reduction potential of plug-in EVs was also studied for Istanbul, Turkey [64].

Kouka et al. have investigated the integration of electric vehicle charging stations with PV as it is both economically and environmentally smart and encourages the utilization of a smart grid [65]. Implementing an energy storage system (ESS) into the charging tools is essential to achieve a balance in power by compensating for PV interruption [65]. In their recent study, Kouka et al. proposed an innovative energy management strategy (EMS) for a residential electric vehicle charging station (EVCS). The idea behind this EVCS is that it was coordinated in a way that made everything instantaneous [65]. The PV or solar power, along with the grid and energy storing system, were all in sync to be as efficient as possible for a residential electric vehicle station. Another feature of this EMS is that it considers and prioritizes cars to maximize the PV available. Everything was considered, including the connection of the PV source, to the energy storage system (ESS), and each parking pattern. The efficiency of this EMS was tested and examined under varying conditions, and took into account the two extremes of the summer and winter seasons [65]. The simulation results during winter showed that there was a power deficit in the first four hours of the winter day, naturally, due to the lack of radiation. This is when the EMS intervenes and allows the ESS to do the supplying instead. When the ESS cannot provide power later at night due to its SOC, the grid takes over and starts supplying the EVs instead, generating the difference [65]. However, on a summer day, the station presents a power deficit from 19 h to 23.8 h. Accordingly, the ESS supplies the connected EVs with power. Therefore, the ESS provides the needed power to the chargeable cars till the morning of the following day, as opposed to on a winter day. This goes on without the need for grid connection due to the irradiance in that period [65].

Kineavy et al. proposed recharging electric vehicles via solar PV station based on inductive power transfer methodology in Ireland. The design incorporated the utilization of a PV charging station to simultaneously recharge four electric vehicles [66]. In another study in the Netherlands, Mouli et al. studied the prospect of charging battery-electric vehicles via solar energy [67]. The authors of the study aimed to find an ideal placement of the PV panels to maximize the energy yield in the Netherlands. They achieved this by comparing the different placements with the use of tracking systems. They also explored the prospects of oversizing the photovoltaic technology collection power levels concerning the power converter size, which depends on the meteorological conditions of the location. Next, they used Gaussian charging to deliver a dynamic charging mode for electric vehicles. This way is grander than simply using constant power charging and evaluating the impact of the grid with different types of workplace charging scenarios and even varying between workdays and running it on a year-round model. In terms of ideal sizing, they considered the meteorological data and smart charging of the electrical vehicles [67]. To decide on the ideal or optimal placement of the PV panels, the authors collected their meteorological data to ensure the maximum energy yield. Additionally, the daily and seasonal changes in solar insolation were considered to ensure the availability of energy necessary for EV charging and the requirement for grid connection. The study reported that if the converter's power supply is considered, the PV array's power valuing can be oversized by a factor of 30%. This is because solar insolation is comparatively low in the Netherlands. Several electric vehicles and their charging capabilities were compared and analyzed to maximize the usage of solar power and reduce the reliance on the grid. To achieve this, the authors had to come up with two different schemes and compare them. The first scheme or scenario was to charge the vehicles solely on weekdays, while the second scenario was to charge the vehicles on all days of the week. A priority tool was applied to assist with charging multiple

vehicles with a single PV charger. The authors assessed the possibility of incorporating local storage into the charger, to make it grid-less. The proposed storage would then be utilized to reduce the reliance on the grid by 25% [67].

The authors provided two vital observations. They reported that the average monthly peak power ranged between 2 kW in November to 7 kW in July. This indicated that the PV system, even in the sunniest month of the year, can only produce 70% of its rated power. The second observation was that PV generation was only available for 7–8 h in the winter months while it was restricted to 15 h in the summer. Hence, due to the mentioned seasonal and diurnal variation in solar insulation, the option for grid connection became essential and acted as an energy buffer. In addition to the grid, local storage in the form of 10 kWh Li-ion batteries was proposed to reduce the load on the grid dependence of the EV–PV charger. It appears that the power exchanged with the grid and the stored energy in the local storage bank for the seven days/week load made the battery empty in the winter months, since no excess PV power is available to charge it. Contrary to the winter months, the battery was kept fully charged during the summer months due to the availability of solar energy. Moreover, the local storage had benefited the design in the case of five days/week EV load even in winter months, as the local storage was periodically charged during the weekends. This also helped to provide enough energy supply to meet the EV energy demands on Mondays and Tuesdays. Nevertheless, the study reported that the storage was depleted for the rest of the week during winter. However, it remained full during summer. The authors also studied the storage size up to 75 kWh since they found that the 10 kWh storage battery was inadequate for making the EV–PV charger independent from the grid. They found that, as the battery storage size increased, the energy exchanged with the grid reduced up to a specific value above which the battery became saturated. This implied that even if the storage capacity exceeded 75 kWh, there was still a minimum amount of energy required to be fed from the grid. This situation could be applied to several locations, such as the Netherlands, which have sunshine and significant differences between winter and summer seasons. However, the authors concluded that despite those limitations, the design of the workplace charging of EVs from solar energy could directly utilize PV power for residential and commercial use.

Mohammad et al. have reported recently on a system where electric vehicles (EV) are connected to the electrical grid. The technology was termed vehicle-to-grid (V2G) since it allows the flow of energy between the grid and EV via the utilization of information and communication technologies (ICT) with the EV charging system [16]. Their proposal addressed the main issues related to the possible decline in stability and interruptions in the system. It also considered the additional costs associated with the increasing level of EV usage which impacts energy and power demand [16].

5.2. Integration with Wind Energy

Very few studies have reported on the integration of EV charging stations with wind energy compared with the studies reporting on their integration with solar power [2]. Al-Wahedi and Bicer proposed a fast-charging electric vehicle station that utilized several renewable energy sources. This included wind, biomass, and concentrated photovoltaic/thermal (CPV/T) sources. The sources were integrated into a hybrid configuration to which several energy storage systems, such as the battery, hydrogen, and ammonia units, were added. The proposed plant had several modes of operation based on the availability of solar, wind, and biomass resources [68]:

- (a) The concentrated photovoltaic/thermal (CPV/T) produced electricity and thermal energy. Hydrogen production, vehicle charging, ammonia production, and the storing battery, in that sequential manner, are all supplied for using the produced electrical power. The aim is to obtain enough electricity from this mode alone; if not, the next mode will take over, supplying the shortfall. It all depends on the amount of electricity produced in a day. The produced thermal energy is used to charge the PCM in the thermal storage unit and to heat the cooling system.

- (b) Following the CPV/T system comes the wind turbine. After the electric vehicle is charged, the battery follows suit. If there is wind, this system works well. This means that energy is being collected through the horizontal axis wind turbine regardless of what time of the day it is.
- (c) When it is night and the wind speed is not at the desired speed level, the Rankine cycle is put to work. This sub-system is biomass-based, meaning that the heat produced through biomass combustion is used for the heat addition process in the steam Rankine cycle, generating electrical power.

The whole system of CPV/T, wind turbine, and biomass-based Rankine cycles was made to prioritize and maximize the usage of solar and wind energy. Therefore, the subsystem of Rankine cycles can even be replaced with a biodiesel generator.

- (d) In case the wind and solar-generated energy is not enough and does not meet the demand available, hydrogen fuel cells are the first line as storage for electrical power production.
- (e) As a second option to hydrogen fuel cells, ammonia fuel cells and ammonia production are then used. Again, this will act as a storage system to produce electrical power.
- (f) Lastly, a conventional battery storage system would supply energy in the chance of shortage, following the first two storage systems prioritized above [68].

5.3. Integration with Hydrogen and Ammonia Energy Carriers

Several studies have reported on the use of hydrogen in which the generated electrical energy was from grid-independent renewable energy sources, such as solar PVs and wind turbines [69]. In addition, fuel cells are also employed to overcome the intermittency issue of renewable sources, such as solar and wind [70]. Hence, hybridizing several energy production methods brings more sustainable and reliable operations. For instance, solar and wind energy systems were hybridized along with hydrogen but there was a battery bank for storing the electricity. In that case, the electricity was supplied to an electrolyzer to generate hydrogen [69]. After that, hydrogen is stored in the tanks and used in the fuel cells for electricity generation. Another study investigated a multigenerational system providing heating, cooling, and electricity supply for buildings with an EV charging station [71]. Therefore, it is evident that there is a need to design, develop, and assess off-grid, renewable-driven, hybrid fuel cell-based EV charging stations to make EV implementation more environmentally friendly and sustainable.

Al-Wahedi and Bicer described a model system with an ideal, stand-alone hybrid renewable energy-based electric vehicle charging station with electrochemical and chemical energy storage. They reported simulations focusing on wind and solar energy as the suggested renewable energy resources, which are abundant and provide enough supply in their chosen location throughout the year [4]. Even on days when the two chosen sources are unavailable, due to natural changing climates, hence, hydrogen and ammonia are produced and stored as chemicals to produce energy interminably. The diagram of the proposed priority scheme, with its hybrid renewable multi-generation system, is shown in Figure 3.

Sare et al. aimed to achieve several objectives when they investigated the potential of integrating EVs with renewable energy in Croatia. The first objective was to produce a system that is 100% sustainable. The second objective was to introduce electrical power to the transportation sector and assess its impact. The last goal was to introduce and integrate renewable energy into the Dubrovnik region up to 2050 by investigating several scenarios based on three tariff models. The authors reported that in the Dubrovnik region, the power systems were secluded and the only storage available for the EVs was their batteries. Therefore, every setting that was examined showed an overload of electric power. This means that there was not enough space to store the excess energy until this was resolved. Hence, the system could not be regarded as a 100% renewable and sustainable power system [2].

Table 3. Summary of the studies that reported on integrating EV charging stations with renewable energy sources.

Reference	Renewable Energy Source	Type of Vehicles	System Advantages	System Limitations
Ou et al. [63]	Solar	Electric & hybrid vehicles	Utilized micro-combined heat and power (CHP) system to achieve higher output efficiency	Limitations related to: (1) solar power uniformity (2) range anxiety issues
Kouka et al. [65]	Solar	Electric vehicles	(1) Serves residential areas. (2) Innovative energy management strategy (3) Serves in summer/winter.	Possible limited grid connection capacity
Kineavy et al., [66]	Solar	Electric vehicles	Able to recharge four electric vehicles	Daily & seasonal changes in solar irradiation
Mouli et al. [67]	Solar	Electric vehicles	(1) Serves workplace (2) Utilizes dynamic charging mode	Daily & seasonal changes in solar irradiation
Al Wahedi et al. [68]	Solar, wind & biomass	Electric vehicles	(1) Maximized utilization of solar/wind & biomass energy sources (2) Hydrogen fuel cells are used to store extra energy	Possible extra cost for supporting system components
Al Wahedi et al. [4]	Wind & solar	Electric vehicles	Energy systems are based on integration with wind and solar power to provide independent systems.	The overall cost of Li-ion batteries usage and the lifetime are based on a limited number of charging cycles
Sare et al. [2]	Hydro, solar & Wind	Electric vehicles	100% sustainable system	Modeling with several assumptions related to lack of data
Farahani et al. [72]	Solar, wind, and hydrogen	Electricity network & Electric vehicles	Affordable electricity supply to office buildings	Several assumptions related to the V2G mode

Recently, Farahani et al. reported on using hydrogen as one of the main energy carriers in integrating EV charging stations with renewable energy systems [72]. Hence, the energy that was once produced through wind or solar energy can be stored later. The fuel cells used to store the energy will then change it back to electrical energy when needed. The authors went ahead and presented their idea to the Shell Technology Center in Amsterdam. They found that the incorporation of EVs into the electricity network currently available in the country was a viable option and even worked as an adaptable energy buffer. They also found that instead of using their battery, they should be using hydrogen and salt caverns as they would be more economically viable. Finally, their system would work well, as both the electricity and hydrogen would not only be feasible integrations but would also be reliable and much more affordable in an office building. The summary of the studies having integrated renewables for electric vehicles is given in Table 3.

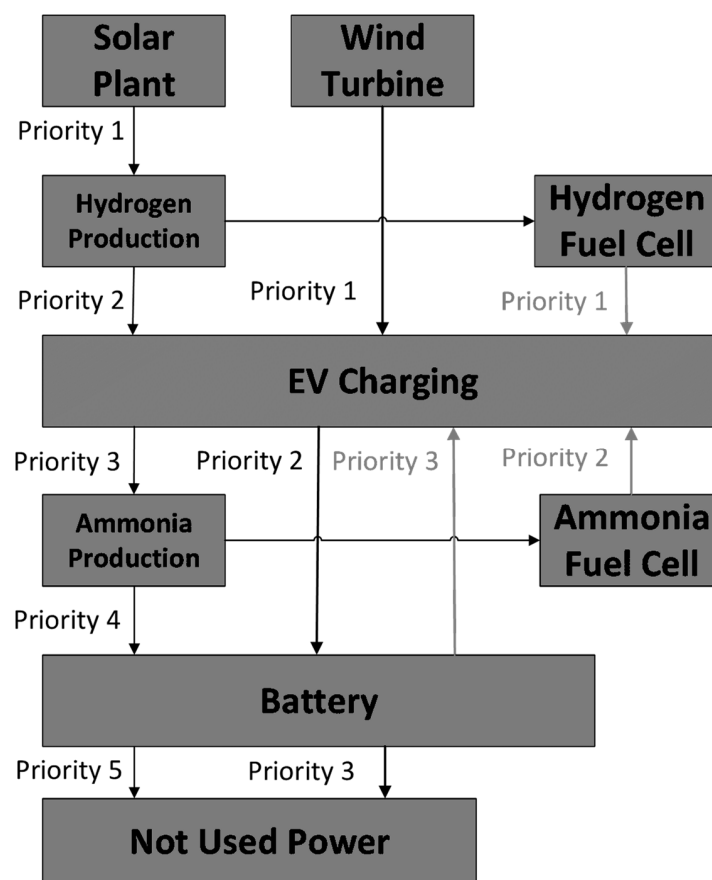


Figure 3. EV charging priority hierarchy levels, adopted from [4].

6. Environment and Sustainability Aspects

Several benefits have been reported on the possible transition to EV transport systems. The reported advantages and gains reflect the impacts generated by reducing the dependence on fossil fuels for transportation [52]. Hence, more government funding can be directed to improve the quality of life in local communities, such as improving schools, infrastructure, and hospitals. These funds shall also drive higher environmental, economic, and social improvements. Moreover, in communities that mainly depend on tourism or agriculture, using renewable energy for transportation and other applications can create more jobs and reduce poverty. In this context, local engineering companies are encouraged to plan, design, and install renewable energy systems for local communities at affordable maintenance contracts.

Moreover, the transition to EV transport mode shall provide an efficient transport system and reduce congestion. It would also encourage tourism as less polluted air shall be obtained.

Another benefit of the efficient utilization of EVs is that it would eliminate the dependence on a centralized distribution grid, especially for remote areas. This would provide locals, and more specifically women, with better opportunities to pursue education and other job offers.

An additional advantage of e-mobility is that EVs can improve grid stability and energy security. If proper policy incentives are implemented, EVs can attract renewable energy generation surpluses by feeding the grid with electricity via the mentioned systems, such as V2G. Other benefits are related to significant cost reduction by providing balancing and supportive services to the grid operator. Moreover, power outages shall decrease over time and renewable energy capacity shall expand. The dependency of the electricity system on diesel generators, for instance, has disrupted economic and social life through several

power outages that were witnessed in the past [52]. Hence, Mouli et al. have summarized several advantages of such an EV–PV charging system as per the following [67]:

- Less energy dependence on the grid due to green energy generation for EVs.
- Using EV batteries reduces the adverse impact of large-scale PV integration in the distribution network.
- The ease of implementation of vehicle-to-grid (V2G) technology is due to the extended parking time of EVs [67].

7. Economic Feasibility Studies

Electrical vehicle charging is regulated through three proposed traffic models. Each model is normally based on two tariffs, a lower tariff and a higher tariff [45]. Tariffs during daylight hours are higher than those after nightfall. This is because electric vehicles are usually charged during the night. To estimate the effectiveness of the V2G technology in the integration with the production of energy from renewable energy resources (RES), specific recreations are carried out for each hour. The charging models vary depending on different arrangements that were studied through their charging patterns. Different combinations of charging models were studied for each scenario that was developed by using assumptions about future happenings. Their effect on the system optimization was studied, and the differences among the varying models and their shifting patterns were examined. Sare et al. looked at their impact on the maximum demand for electric power and how it related to production from RES. The models and their formulae were described exactly how they were in the Energy PLAN manual [2].

The economic aspect of using electric and green vehicles is mostly intensified by the cut in costs related to the burden of disease caused by air pollution. The move for zero-emission driving shall reduce the adverse health impact and enhance social development. This is attained through improved welfare and, consequently, minimal loss of working days, premature mortality, and hospitalization costs. However, there has been an argument related to the social impact of using electric vehicles related to the potential exploitation of child labor, such as the extraction of cobalt from mines in Africa where incidents have been reported in the hand-mined sites [73]. Cobalt is a key component of the electric battery (lithium-ion batteries) that are used in EVs and is majorly extracted from mines in the Democratic Republic of Congo. Recently, Omahne et al. studied the social aspects of using EVs in the context of sustainable development. The authors divided the social factors into five categories, where cost was one of them [74]. The authors showed that what would make EVs socially cost-competitive depends on several parameters, such as the marginal cost of electricity needed to charge the vehicles, aiming at developing a comprehensive optimization model to minimize the annualized cost of charging and using EVs. Further social benefits can be associated with fewer traffic accidents due to reduced visibility when high levels of particulate and gaseous traffic emissions are achieved.

However, the cost associated with environmental and ecological protection is more significant in the long term due to zero emissions from these vehicles. However, at the manufacturing stage of electric vehicles, there is environmental pollution and adverse impact due to the need to use many chemicals and metals specific components of the electric power parts, such as the high-voltage battery. Another environmental improvement gain is related to developing electric cars with less noise levels. Nevertheless, the significant gain of using EV is the zero emissions, which reduce the concentration of particulate matter and other gaseous pollutants and consequently reduce their critical adverse impact on the air, water, and ecosystem. In addition to the direct reduction in pollutants, several cost-related benefits are associated with preserving welfare due to a clean environment, such as less maintenance of buildings, paints, and surfaces when less PM and SO₂ pollution from transport is attained.

8. Renewable Integration Challenges

Renewable energy is not easily incorporated or integrated into the already existing electric power systems. Since electric power systems are ingrained into our lives and since renewable energy is varying and unreliable compared to our existing methods, it is technically and economically difficult to take such steps. In trying to apprehend the effects of such a move, we need to first understand the three main operational planning scopes that are crucial to renewable integration. After this, we can start to consider how renewable resources affect these planning processes [75].

8.1. Operation of Charging Stations

Several activity stability issues must be considered to ensure that the system's main parameters, including voltage and frequency, are suitable for sustainable operational use. Moreover, the real-time active and reactive power demand and supply must be balanced. The first level of operation should include the supervision at the seconds and milliseconds time scale. The following level involves unit commitment, economic dispatch, and finally optimal power flow analyses. Unit commitment decides which generators must work at each time step within the planning scope to serve predicted demand at minimal cost. They are performed on an hour-to-week-ahead basis. A day-ahead unit commitment that models hour-long time steps is also critical, considering possible fluctuation between power systems.

When the unit commitment model finally decides on the status of each generator and whether it is on or off, the generator's energy production must be chosen. The resulting power flows on the transmission network elements modeling are performed in an economic dispatch model to ensure that they are within the physical limits of the system. This can also be completed an hour ahead or even in numerous systems. The transmittance is also refigured systematically and regularly every five to fifteen minutes, with the most newly made available system information. All three of the real-time dynamic stability, daily economic dispatch, and unit commitment depend on one another. They all help each other get the work done. The unit commitment model, for example, accounts for both the real-time dynamic and the economic dispatch. It has a primary power stream or flow to guarantee that the system is practicably transmitted without imposing transmission limits. To guarantee excess capacity and competency for ramping, the model contains reserve requirements. This helps aid load or capacity under any unforeseen or unexpected happenings.

Normally, the types of failures that are expected or anticipated are to do with generator failures or sudden load increases. Considering limitations in the operational models, the committed generators are required to deliver exceptional and better-quality reserves with exceptionally fast response times.

The last stage of the planning level is concerned with long-term power generation and transmission investments. Sometimes investment decisions are made very early, even a decade before a project is completed. This is because of the possible long lead times associated with such projects. This lead time is often not the fault of the transmission construction but due to finalizing regulatory approvals, receiving adequate financing, and even encountering local opposition. Because investments have to be made while predicting the future and its demands for electrical power, and since these demands have to be accounted for in the assets installed in the system, there are many interdependencies in long-term planning. Therefore, it is essential that investment planning also has the unit commitment, power flow, dynamic stability, and dispatch analyses all incorporated and accounted for. Practically, costs are based on the capital and operating costs of different generation technologies and the load-duration curves. In the case of generator and transmission failures, these might also be investigated with reliability models to decide the additional capacity that should be added to serve the load reliably [75].

However, handling electric vehicle charging stations that are grid-connected is challenging. This is primarily due to the varying prices of grid electricity and the considerable power demand of the large EV fleets. Therefore, many analyses and studies have delved

into diverse charging strategies to help reach the ideal management and scheduling with a focus to integrate PV power and lessen the use of CO₂ and its effects on the environment.

By considering the utility demand response and the dynamic electricity tariff at the same time, the coordination of the electric vehicle charging is calculated based on a real-time charging scheme to exploit the number of vehicles that are scheduled for charging with a reduced charging cost.

To moderate the peak load, two schemes were suggested based on the disruption or the change in the vehicle charging power using binary linear coding to manage the vehicle's charging. Mixed-integer linear programming was also used to elevate the level of satisfaction of EV owners in terms of meeting all charging and discharging requests to lower the operational cost of the parking station as a whole by increasing the use of PV power, energy storage systems (ESS), and planning the charging/discharging of every vehicle [76]. The customer gets to choose the charging amount from five discrete charging levels. This is because the vehicle charging power distribution was enhanced in a commercial parking lot using linear programming [77]. The developed model had future predictive control. This allowed the total benefit of the PV-grid workplace parking lot to be amplified entirely using a vigorous charging plan, as was also examined in [78].

The studies that were reported so far have focused mainly on the commercial usage of charging stations and the absence of discussions on how charging would take place at a residential station. However, Zhang et al. aimed to increase the electric vehicle's autonomy to more than 500 km to minimize anxiety and encourage public use [78]. This also means that residential and private charging would be unnecessary as public EVs would be widely available. Furthermore, residential stations are not as easily studied as commercial ones. The main research reported in this domain was performed with a long time resolution, which impacts the management system's feasibility due to the fluctuation in solar power [79]. Thus, it is critical to consider dealing with the real-time information of the EV charging needs to allow an immediate power distribution to every EV based on its initial and required SOC, the removal time, and its battery capacity [65]. In sum, the economic enticement and CO₂ offsets for PV charging appear to be greater than charging the EV from the grid [67], as shown in Columbus and Los Angeles [79,80].

8.2. Effects of Renewable Energy Sources on Charging Stations Operations

Electric power systems are complicated on their own; incorporating renewable energy sources into the equation will only add to the complication of this field. Renewable energy adds to supply-side inconsistency. Sustaining the balance between real-time energy supply and demand while maintaining stability is challenging. It takes too many hours to get some generators operating. Therefore, the generators that are committed require enough volume capacity to ramp. Without this, they would not be able to counter any unexpected reductions or developments in renewable energy availability. Regulating reserve requirements in the plan is one way to guarantee flexibility or just rely on reserve or flexibility products. Wang et al. investigated the benefits of this constraint on the operation and compared it to other renewable planning ways [81]. Initially, the requirement of a real-time transition constraint guaranteed that the generators committed would have the adequate ramping capability to deal with all the expected supply shortages in the five- and fifteen-minute-ahead dispatch processes. The California ISO proposed adding it to the day-ahead unit commitment, but only when this constraint was finally integrated into real-time operations. However, it is not just about the challenges in planning; economic repercussions come along with the operational variations. Flexibility means additional costs. Flexible or easy-to-work-with natural gas and oil generators imply that they are used and relied upon by different power systems today. While this can increase the operating cost, it can also lower the competence of the generators. Renewable investment affects generation investment in several ways. The first challenge is that it must incorporate the limited ability of variable renewable sources to serve the target load reliably. It was found that the marginal capacity value of the first boost of wind ranges in a scope of 15% to

50% of the nameplate capacity of the wind plate. However, the more wind enters the system, the less the marginal capacity. Analyses of solar energy systems revealed greater capacity values than wind [75]. This is because there was more coincidence between solar accessibility and electricity demand in several power systems. Since all the extra generated capacity must be constructed, if the capacity contribution of renewables is underestimated, this can cause higher rate-payer costs. Equally, overestimating their capacity contribution will ultimately decrease system reliability, because this means that insufficient dispatchable generation will be constructed. Renewable energy can also distort the combination of generators that are put in place, but this will depend on how doubt is dealt with and handled in the day-ahead and real-time operational horizons. As the infiltration of renewable sources grows, the system would need to input more generators, but this is only if it relies wholly on adaptable conventional generators to accommodate its renewable energy sources. As an example, Demeo et al. noted that a gas turbine, purposely created to offer these flexibilities, is currently implemented in the works by a major manufacturer [82]. Incorporating or integrating renewable energy will demand significant investments in transmission facilities. This is because the wealthiest renewable resources in the world are usually very far away from the urban areas, the more populated areas with much more electrical power demand. The results reported an estimate that ranges between 10–200 million MW-miles of transmission capacity to deliver this amount of renewable energy to customers [75].

9. Implementation Issues

9.1. Consumer Incentives and Business Models

When considering the consumers' perspective, one must evaluate the different ways in which they are affected by such a change. One way a consumer's behavior is affected is the plug-in electrical vehicle or the PEV. This is very different from a gas station where the car is fully functioning after a few minutes; in this case, the consumer would have to accept yielding control of their vehicle and allowing a manager at a charging station to take care of it. To allow the consumer to be in full control of their vehicle, price signals are used, and they would be a good enticement, but the consumer might have a hard time realizing the benefits of their options. This is because of difficulties in structuring dynamic prices that achieve socially optimal charging behavior avoiding centralization issues. Therefore, it is understood that the likelihood of a consumer accepting the third-party PEV control depends on how much control they lose over their vehicles and the level of incentives they receive. The incentive they would expect cannot exceed the total value of the services from the charge time-shifting and or power supply that it provides. The consumer, or vehicle owner, could also need an incentive that amounts to zero. This would be the case if the service does not impose anything that would be inconvenient to them or make them feel as though they are ceding their power. If the user or owner wants nothing in exchange, the compensation methods would have to be created according to the client and the service being provided. It is a rather complex process to calculate the precise cost saved by shifting PEV load or the provision of short-term reserve energy, making it almost impossible to price services per transaction. It would only make the calculations even more complicated because the price of electric power would have to depend on the type of service provided, instead of it being a fixed number. The only solution adequate to solve this issue would be then to use fixed, fee-based pricing. Another way to look at this would be to introduce long-term contracts. This could work depending on how flexible the owners or drivers of the vehicles are concerning interruptions and unexpected circumstances [75].

Incentive pricing and taxation shall apply to all users of different clean vehicles, and pricing and taxes are both policies that have been looked into for the promotion of sustainable mobility [83]. Pricing can be placed on parking and while on the road. This is done by charging the user a special price just for entering an area or parking their car there. The point of this is to make private car ownership difficult and expensive, dissuading the public from owning cars and moving instead to public transportation or walking,

promoting sustainable mobility. Road pricing can also be a way to protect the environment and in this case, the price being charged depends on the environmental compatibility of the vehicle. Similar to the case of the Ecopass in Milan [84], one of the broadest and best-known applications is the congestion charge in London, which has been very well investigated [85]. Pricing on the road as an aim for sustainable mobility should connect to the concept of external costs, considering it is not possible to charge the consumer for all the external costs that their car produces. In addition, parking pricing and road pricing policies are often considered second-best methods. Charging parking prices is assumed to be a widely used concept. Many countries worldwide opt for it, especially those of the west, since it charges depending on the minute or hour spent [8].

Another concept widely opted for in the west compared to the rest of the world is taxation on the use of fuel and vehicle ownership [86]. It is generally based on the amount of gas being emitted. This is thought to reduce private car ownership due to the expensive costs it loads, especially on cars that are known to produce sizeable environmental impacts [87]. Therefore, buying EVs will allow them to avoid the hefty costs they would have to spend otherwise. To further promote public transport modes, some countries have required variable costs and increasing fuel taxation chosen instead of fixed costs [88]. Hence, instead of the consumer having to pay one-time fees, they are now required to pay based on the number of trips they take, forcing the consumer to think about spending every time they choose private transport. Selling the idea of low-polluting vehicles is also another incentive that can be investigated. Consumers might prefer to act more responsibly towards the environment and choose sustainable mobility. There are other types of incentives for purchasing a low-polluting car, such as purchasing a new car following the scrapping of a polluting car, switching to an electric car, or even just converting a petroleum car into an LPG (liquefied petroleum gas) car. Governments promote the use of electric cars more to support the automobile industry than to contribute to sustainability [89]. Low emission cars are incentivized to reduce the purchase cost of EVs which currently have no competition. This helps in allowing the consumers have a variety of options to choose from. LPG cars are specifically incentivized to reduce particulate matter emissions in congested areas and urban vicinity [8].

9.2. Charging Stations Infrastructure

Incorporating services to help fully integrate renewable resources from PEVs requires much research on new infrastructure that will allow the EV to connect to the home charger and the system operator (SO). Direct communication between vehicles and SOs is possible, which can be seen through recently developed standards, such as IEC 618511. The first thing to consider is the legality of the move. Much legal work needs to be put in place before implementing the business models can ever fully take place. Many stakeholders need to be addressed. For starters, cars are normally manufactured as one unit where the software and communication network are contained within the vehicle and are complementary to each other [75]. This is an excellent example of where the law would need to work around such statements to allow specific business models to get implemented [75].

Ogden et al. have compared the refueling structure requirement for fuel cell vehicles based on fuel type [90]. They compared the infrastructure needs for four fuel options that included gasoline, compressed H₂, methanol, and synthetic liquids derived from natural gas. The capital cost for building a hydrogen refueling system was estimated to be USD 310–620 per vehicle. However, gasoline refueling stations' capital costs have been around USD 50/vehicle. The same value was estimated for methanol refueling stations. In addition to challenges related to capital cost, other infrastructure challenges are related to the transportation mode of these vehicles—whether they are to be transported from their original production site to the refueling station by trucks or pipes [90].

The consideration of natural gas vehicle refueling stations should be closely established in coordination with local governments. Several steps and procedures require governmental approval during the establishment stage of a natural gas refueling station.

These include proper site location selection, project verification, and quality supervision and inspection. This is because such an infrastructure considers that urban land should be allocated and approved for this application. Such approvals have been reported to take a long time and hence affect the period of the overall project lifetime. Moreover, since these projects are subject to financial losses due to possible drops in NG prices, the governments are encouraged to offer financial incentives for land use, preferential policies, and administrative support for natural gas refueling station operators [14].

10. Conclusions and Recommendations

The growing traffic jams in urban areas due to the excessive use of individual vehicles and fossil fuels have damaged the environment and human health. To reduce the greenhouse gas emissions from the transport sector, electric vehicles should be integrated with renewable energy resources. This review shed light on the primary air pollutants that are increasing due to urban traffic emissions. It also provided an overview of the main types of green vehicles related to electric, hybrid, and fuel cell vehicles. It was emphasized that to achieve 100% sustainable urban mobility, electric vehicle charging stations should be integrated with renewable energy resources, such as solar, wind, and hydro, as well as with other energy-carrying modes, such as hydrogen and ammonia.

Several studies have shown that it is possible to develop efficient EV charging stations integrated with renewable energy that can be utilized in residential and commercial locations. The results obtained in this review show that green vehicle charging stations can be built off-grid and on-grid. On-grid electric vehicle charging stations are more favorable due to their efficiency and continuity in energy supply. On the other hand, off-grid charging stations have been recommended for remote locations to encourage and increase the use of electric vehicles. Moreover, the integration with solar energy was found to be more favorable since it is available at no cost. However, solar energy supply might be interrupted during winter and at night. The integration of EV with wind power showed that the system shall work well if wind is available. The integration with hydrogen and ammonia carriers needed a special design as both carriers need to be produced and stored. However, several challenges related to the fluctuation in solar radiation and wind availability have been raised. To address these shortcomings, additional system components, such as a battery for extra energy storage, were recommended.

The main findings from this review study are listed as follows:

- Urban air quality should be improved by replacing current high carbon-containing fuels in the transportation sector.
- Each fuel (e.g., gasoline/diesel) replacement alternative (e.g., natural gas, hydrogen, electricity) will bring additional infrastructure and modifications to existing systems, such as new storage tanks, new delivery trucks, and new transmission lines. Therefore, the overall feasibility of the investment shall be carefully studied, including the environmental and social costs.
- Renewable energy resources should be integrated into the supply chain of these alternative fuels so that the overall carbon footprint can be diminished. As an example, EV charging can be satisfied by solar- and wind-based electricity.
- Future clean transportation means will need more energy storage due to flexibility, low mileage, smart cities, and energy trading. Hence, on-site energy storage in alternative fuel stations should be carefully studied to minimize the losses and maximize the energy delivery to the vehicles. This can include battery electricity storage, hydrogen/ammonia/natural gas storage, as well as peer-to-peer energy trading.
- Integration of renewables to urban transportation can bring several challenges, such as fluctuations in voltage and frequency, day-ahead scheduling, sudden load increase due to rapid charging, charging price fluctuations, and real-time data acquisition from the clean vehicles.
- The rapid transition to clean transportation in urban cities is a tangible and promising solution to mitigate climate change and improve air quality.

The research in this field is quite active and developing worldwide, hence; several recommendations can be suggested for future work. Some suggestions can address the implementation of appropriate frameworks to propose several incentives for the consumers to encourage them to use EVs. Since the integration with the system and the availability of refueling stations require high capital cost, land availability, and infrastructure compatibility, it is critical to obtain support and approval from the local governments from the beginning. Additionally, smart charging algorithms should be developed to address multiple charging powers and meet the market's needs. More research is also required in connection to the grid, which also entails a fluctuation in electricity prices.

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Nomenclature

Abbreviation	Meaning
As	Arsenic
BEV	Battery electric vehicles
Cd	Cadmium
CHP	Combined heat and power
CO	Carbon oxide
CO ₂	Carbon oxide
CPV/T	Concentrated photovoltaic-thermal
dB	Decibel unit
DOCF	Diesel oxidant catalyst filter
EM	Electric motor
EMS	Energy management strategy
ESS	Energy storage system
EU	European Union
EV	Electric vehicles
EVCS	Electric vehicle charging station
FCV	Fuel cell vehicles
EPA	Environment Protection Agency
GCC	Gulf Cooperation Council
GHG	Greenhouse Gas
HEV	Hydrogen electric vehicles
HFC	Hydrogen fuel cells
HFCV	Hydrogen fuel cells Vehicles
ICE	Internal combustion engine
ICEV	Internal combustion engine vehicles
ICT	Information and Communication Technologies
IEA	International Energy Agency
IEC	International Electrotechnical Commission
ISO	Independent System Operator
kW	Kilowatt
kWh	Kilowatt-hour

Li-ion	Lithium ion batteries
LPG	Liquified petroleum gas
LPGV	Liquified petroleum gas vehicles
NG	Natural gas
Ni	Nickel
Ni-MH	Nickel-metal hydride
NO _x	Nitrogen oxides
NO ₂	Nitrogen dioxide
PAPA	Public Health and Air Pollution in Asia
Pb	Lead
PCM	Phase change material
PFF	Partial flow filter
PHEV	Plug-in hybrid electric vehicles
PM	Particulate matter
PM _{2.5}	Particulates of diameter equal to or less than 2.5 micrometer
PM ₁₀	Particulates of diameter equal to or less than 10 micrometer
PV	Photovoltaic cells
RBS	Regenerative braking system
RES	Renewable energy resources
SO	System operator
SO ₂	Sulfur dioxide
SOC	State of charge
US	United States
USEPA	United States Environmental Protection Agency
V2G	Vehicle-to-grid
WFF	Wall flow filter

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