sustainability

MDPI

Article

Affordable Electric Three-Wheeler in Bangladesh: Prospects, Challenges, and Sustainable Solutions

Md Junaed Al Hossain [1], Md. Zakir Hasan [1], Md Hasanuzzaman [2,*], Md. Ziaur Rahman Khan [3] and Mohammad Ahsan Habib [4]

[1] Department of Electrical and Electronic Engineering, Daffodil International University, Dhaka 1341, Bangladesh
[2] Higher Institution Centre of Excellence (HICoE), UM Power Energy Dedicated Advanced Centre (UMPEDAC), Level 4, Wisma R&D, University of Malaya, Jalan Pantai Baharu, Kuala Lumpur 59990, Malaysia
[3] Department of Electrical and Electronic Engineering, Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh
[4] Department of Mechanical and Production Engineering, Islamic University of Technology, Gazipur 1704, Bangladesh
* Correspondence: hasan@um.edu.my or hasan.buet99@gmail.com; Tel.: +603-2246-3405

Abstract: With rapid urbanization and population growth, there has been a significant increase in the demand for public transport. Fossil-fuel-based internal combustion vehicles are increasingly fulfilling the transport demand and are creating negative impact on the environment. Electric three-wheeler (E3W) vehicles have better prospects in public transport in Bangladesh. The demand and usage of E3W vehicles are increasing rapidly because of their pollution-free and passenger-friendly services. However, there are many challenges, including vehicle stability, regulation, energy supply, battery disposal, etc. This paper discusses the prospects and challenges of the E3Ws in Bangladesh in terms of technological and environmental aspects. The paper addresses the issues of E3W, such as existing structural problems, inherent limitations, consequences of uncontrolled battery charging, and improper battery disposal. Potential solutions to tackle these challenges have been suggested for future sustainable transport in Bangladesh. An overview of existing policies regarding E3W in Bangladesh has been presented, and some recommendations have been made to facilitate the integration of E3Ws in the public transport domain. A review of the technologies can provide a base for strategic E3W policy for the next generation of sustainable transport policies and can help policymakers to frame strategies aiming for clean technology and sustainable development of the transportation system in Bangladesh.

Keywords: battery; battery disposal; electric three-wheeler; electric vehicle; energy

check for updates

Citation: Hossain, M.J.A.; Hasan, M.Z.; Hasanuzzaman, M.; Khan, M.Z.R.; Ahsan Habib, M. Affordable Electric Three-Wheeler in Bangladesh: Prospects, Challenges, and Sustainable Solutions. *Sustainability* **2023**, *15*, 149. https://doi.org/10.3390/su15010149

Academic Editors: Noradin Ghadimi and Alberto-Jesus Perea-Moreno

Received: 2 October 2022
Revised: 28 November 2022
Accepted: 13 December 2022
Published: 22 December 2022

1. Introduction

Rapid urbanization and industrialization call for higher mobility in the transportation sector, especially for developing countries such as Bangladesh. With the increasing demand for transportation, the dependency on fossil fuels increases, further worsening Bangladesh's air pollution problem. According to World Air Quality Report 2021 [1], the average annual particulate matter 2.5 (PM 2.5) concentration in Bangladesh is 76.9 μg/m^3, which is more than 50 times of World Health Organization (WHO) guideline (0–5 μg/m^3) making Bangladesh the most air-polluted country in the world. Fossil fuel-run vehicles account for 80% of air pollution [2], likely to persist or rise with increasing dependency on fossil fuel-run transportation [3]. Replacing the ICE vehicles with battery-driven electric vehicles can tackle the air pollution problem, as the electric vehicles are inherently tailpipe emission free [4]. Unlike in the developed countries, Bangladesh lacks proper infrastructure and policy for electric mobility in public and private transportation. Despite limited scopes, the electric three-wheeler (E3W) vehicle has come out as a potential solution to tackle the air pollution problem and meet the higher mobility transportation demand, especially for the non-metropolitan areas of cities, rural and suburban areas. Currently, E3W is being perceived as a major form of public transport, mostly in suburban and rural areas in Bangladesh. Besides Bangladesh, these vehicles are widely used in countries such as India, China, Nepal, Thailand, Indonesia, Philippines, Tanzania, etc. [5–10] in various names such as Easy Bike, E-Bike, E-Trike, Auto rickshaw, City Bike, etc. [11–13]. The E3Ws have received wide acceptance mainly because of inexpensive fare rates, smoke- and noise-free service, and the ability to cope with rough road conditions. They are also a source of employability for many people [13,14]. However, integrating the E3Ws with the public transport sector brings about challenges raising concerns over sustainability. In the near past, the primary concern was the significant demand for electricity for charging purposes, which remains to date [15,16]. However, today, the focus has shifted toward the fact that these vehicles are prone to accidents, and the number of passengers suffering physical disability from the E3W vehicles is also increasing day by day [17]. The main reasons identified are these vehicles' poor braking and suspension systems [14]. The E3Ws are accident-prone and frequently cause traffic congestion. The life span of the E3Ws significantly reduces by the substandard quality of the battery charger [8]. Despite being environmentally friendly, the improper battery charging and disposal of batteries cause pollution, which harms human health [8,14]. However, despite the problems associated with the E3Ws, a complete shutdown of these E3Ws usages is very unlikely, considering their socioeconomic aspects. Research is being conducted to address the issues related to the E3Ws. There are research studies regarding the braking and suspension system of the E3Ws [18,19] and the frame design of these vehicles [11]. The authors of [15,16] show how overnight charging of E3W is likely to impose negative pressure on the national grid in terms of high-power requirements. Demand-side management proposes to mitigate such a problem [20]. Renewable energy can incorporate into the charging infrastructure of the E3Ws [5,21–23]. The socioeconomic aspects show why electric three-wheelers are so popular among middle- and low-income earners in urban and rural areas [24,25]. Various types of research have been conducted to highlight different factors associated with the E3Ws. However, these factors are mostly interdependent. For example, the battery capacity and motor quality determine the possible range of the E3W vehicles [26]. Battery health depends greatly on the quality of the charger [14]. The charger and battery capacity determine these vehicles' energy consumption, which impacts the grid [20]. Moreover, the safety of the passengers and drivers depends on the proper functioning of these vehicles' braking and suspension systems [18,19,27]. However, such interdependency of these factors of E3Ws has not been broadly explored.

The number of E3Ws is increasing t" mee' the passenger's demand for affordable and noise- and pollution-free transportation. It is vital to investigate the prospect and challenges that E3W possess to facilitate a robust integration in public transportation. The authors feel the necessity of concrete reporting on the E3W that considers all aspects of E3Ws in light of a developing country such as Bangladesh. Therefore, the research aims to present the prospect and challenges of E3Ws in Bangladesh and explore the feasible and sustainable solutions to the challenges so that the policymakers can be facilitated to develop infrastructure, policies, and schemes to regulate the increasing number of E3Ws successfully. The novelty of the work is that it draws an overall picture of E3Ws, including its prospect, challenges, and possible solutions in light of Bangladesh, which can provide necessary insight to the general public, researchers, and policymakers of Bangladesh and other countries. The contributions of this work to the scientific community are pointed out below:

- Exploration of the prospect of E3Ws in Bangladesh, which can be assessed in other developing and underdeveloped countries;
- Proper information on E3Ws technical components and their current attributes;
- Investigation of the possible challenges of E3Ws in technical and environmental aspects;

- Propose feasible and sustainable solutions to the challenges that are under present Bangladesh's socioeconomic condition;
- Overview of current and proposed policies concerning E3Ws;
- Propose recommendations for the policymakers to facilitate their decision making;
- Figure out the possible direction for future research regarding E3Ws.

The paper is designed as follows. Section 2 presents a literature review. Section 3 provides the prospects of E3W in Bangladesh. Section 4 provides an overview of technologies associated with E3Ws. Section 5 describes the methodology adopted in this work. The findings on the critical challenges of E3Ws in technological and environmental aspects and their respective possible solutions are presented in Sections 6 and 7, respectively. Section 8 details the policies associated with E3Ws and recommendations for policymakers. Section 9 points out the scope for future research. Finally, Section 10 concludes.

2. Literature Review

E3Ws are a distinct category of electric vehicles (EVs). While there is no thorough investigation on the prospect and challenges of E3Ws considering the various aspects of a country, there has been research regarding the adaptation of other types of EVs in different countries in the world. An overview of EV prospects and challenges in developing countries has been explored in [28], where the authors have focused on electric four-wheelers (E4Ws) and electric two-wheelers (E2Ws). The authors in [29] have performed a survey-based study on the prospect and challenges of electric vehicles in southeast Asian countries to facilitate policymaking and have highlighted issues that can hamper electric vehicle adaptation in those countries. The challenges of EV adoption in India have been explored in [30], where the authors discuss the challenges involving financial and technological aspects while exploring possible solutions. An overview of the challenges of implementing the electric vehicle culture in Malaysia has been presented in [31]. The authors in [32] investigate factors that facilitate the adoption of EVs in Ireland, where the authors highlighted the socio-demographic, psychographic, and behavioral factors that have influenced EV uptake. This research in [33] analyzes the factors that motivate the technically sound customer to adopt EVs while providing engineers and policymakers with critical information for developing future electric vehicle technology. Government intervention to facilitate EV integration in Japan has been discussed in [34]. The authors in [35] provide an assessment of the strengths and weaknesses of China's electric vehicle technologies and industry. An overview of EV technologies breakthrough, industrialization, and government policies in China has been provided in [36]. The authors in [37] provide a comparative analysis of consumer adoption of EVs in the United States and China despite having similar EV subsidies. There have been some works that focus on specific aspects of E3Ws in Indian aspects. The authors in [7] present an overview of E2Ws and E3Ws in India. The potential of E3Ws as a source of employability has been discussed in [13]. The authors in [38] present a techno-economic assessment of electric motors for E3Ws. The environmental aspects of E3W adoption in India have been explored in [39], where the authors show the reduction of emissions with systematical adoption of E3Ws in light of real-world drive cycles.

3. Prospects of Electric Three-Wheelers in Bangladesh

E3Ws were first introduced in 2004 and were fully marketed by 2008, and around 1 million E3Ws are currently active in Bangladesh [15]. These vehicles play a significant role in transport for short distances and intra-city transport systems in almost all major and minor cities in Bangladesh. They fill the gap created because of either lack of conventional public transport or their substandard performance. The E3Ws are suitable for regions with low overall traffic speed [40]. These vehicles have low operating and initial costs resulting in a pretty reasonable fare for the riders, and passengers can have their desired noiseless and smoke-free journey. An E3W can carry six to eight people at a time. Sharing the ride is one of the distinctive features that make this transport more popular, as it reduces per-head fare for the passengers. E3Ws roughly transport around 25 million passengers per day in Bangladesh [41,42]. They have also become a viable source of employability for many people [13]. It is estimated that E3Ws have provided employability to around 3 million people, including drivers, assemblers, repairers, and automotive industries [42].

Conventional ICE vehicles are considered one of the significant sources of greenhouse gases leading to global warming [43]. Fossil fuel exploration for ICE vehicles link to global warming, which has become a significant concern, as the usage of such vehicles is causing environmental degradation [44]. With rapid urbanization, motorization is increasing, causing significant air pollution in the cities [23]. Bangladesh is currently battling the world's worst air quality, where its capital Dhaka is the second most air-polluted city in the world [1,2,45]. Thus, environmentally friendly transport is imperative to the health of hundreds of millions who dwell in densely packed cities [8]. Therefore, E3Ws can be considered as a potential solution, as they use electricity for charging purposes and are free from emissions. They consume lower energy than their ICE counterparts while providing similar performance with the same weight [19]. Besides being environmentally friendly, E3Ws are more economical than CNG-operated auto rickshaws. E3Ws are considered a potential alternative to CNG and LPG-based three-wheelers. These CNG and LPG-based vehicles have a top speed of 55 km/h [23] and carry up to four passengers and cargo. The speed is higher than E3Ws, which have a top speed of 40 to 45 km/h [12]. However, CNG and LPG are non-renewable energy sources. Using such vehicles increases the dependence on depleting fossil fuel reserves and contributes to pollution problems by emitting pollutants such as CO, HC, NO_X, etc. On the contrary, E3W is tailpipe emission-free. As a result, these vehicles do not have a negative impact on the environment as well as public health. In addition, shifting toward E3W from CNG and LPG-based three-wheelers will reduce overall emissions from the public transportation sector [39]. E3Ws are also gaining popularity over conventional CNG-operated auto rickshaws from an economic perspective because of the low manufacturing cost, maintenance, and daily expense of the driver. An approximate cost comparison between a battery-powered E3W and a CNG-powered auto rickshaw in 2013 has been presented in [25]. Table 1 shows the corresponding comparison with the current inflation rate of Bangladesh [46].

Table 1. Cost comparison between an E3W and CNG operated auto rickshaw (adapted from [25]).

Factors	CNG Operated Auto Rickshaw	Battery Operated Electric Three-Wheeler
Maintenance Cost (Monthly)	60–80 USD	40–60 USD
Daily Income (Driver)	20–24 USD	14–16 USD
Daily Expenses (Driver)	4–5 USD	3–4 USD
Owner Daily Income	800 BDT (10 USD)	560 BDT (6.5 USD)
Retail Cost (With Assembly)	6000–8000 USD (from India), 6000–7000 USD (from China)	2375–2625 USD (from China)

Table 1 shows that an E3W has a manufacturing cost of approximately two to three times lower than a CNG-operated auto rickshaw. Although the average income of a CNG auto rickshaw driver is slightly higher than the E3W, lower maintenance costs and lower daily expenses by an E3W driver compensate for the overall total cost of ownership. In addition, the drivers are likely to favor the E3W over the CNG-operated auto rickshaw for the promise of reduced fuel cost at constant investment cost [9].

The CNG auto rickshaw's fuel economy ranges from 35 to 40 km/liter gas. Fuel consumption varies with the transport demand. The availability of gas filling stations enables the CNG auto rickshaws to have a comparatively higher range than E3Ws. E3W energy consumption is about 14 km/kWh (e.g., maximum range 150 km [14] with an overnight charge of 11 kWh [20]. However, CNG auto-rickshaws and E3Ws are mainly used as intra-city transportation media and travel almost identical distances on average. Therefore, the higher mileage of the CNG auto rickshaw does not have a significant advantage over E3Ws. As the transport demand is significantly high from day to evening time, E3Ws can conveniently meet the demand from day to evening time while overnight charging [20,25]. Moreover, the batteries of an E3W can be used as a power supply to meet emergency demands. An E3W can work both as a power supply and as a mobile power supply carrier to meet the emergency requirement where a sudden arrangement of the generator may not be possible [47].

4. Current Electric Three-Wheeler Technologies

E3Ws are imported from China or locally assembled with imported or locally manufactured parts in Bangladesh [20]. China is the largest manufacturer of E3Ws and associated parts of these vehicles. The common models of E3Ws available in Bangladesh are Xinge, Dowedo, Jet Fighter, Mainbon Group, Gangchill, Xingebang, Jt Tricycle, Porag, and Bagh [48,49]. This section presents an overview of E3Ws structure and technologies used in Bangladesh.

4.1. Structure

E3Ws are generally recognized by their tin/iron body [12] as well as fiber-glass bodies. The constructional aim of the E3W is to provide strength, durability, aesthetic look, lightweight, and low maintenance [7]. It has one wheel in front and two at the back. It has a seat for the driver with a passenger in the front, and in the rear, there are one or two benches covering a seating arrangement of three to six passengers. An E3W has an open door for both the driver and the passengers and thus allows for immediate pick-ups and drop-offs [12]. The compact size and three-wheel mobility are suitable for flexible maneuverability on urban, suburban, and even rural roads [11]. The most common E3Ws are Easy Bike and Mishuk in Bangladesh. The size and power requirements of Easy Bike are comparatively higher than Mishuk. Figure 1 shows these two types of E3Ws.

(**a**) (**b**)

Figure 1. Electric three-wheelers: (**a**) Easy Bike (**b**) Mishuk.

Mishuk, as a comparatively smaller E3W, can carry around 3–4 passengers. Mishuk requires four batteries compared to five batteries for an Easy Bike and, therefore, requires lower investments than an Easy Bike. Mishuk is suitable for the traffic-congested urban environment for its compact size. However, Easy Bikes are more suitable for suburban and rural areas and can carry around six to eight passengers. An Easy Bike has higher operating power and ground clearance than Mishuk, making it highly suitable for rural and semi-urban roads. This paper focuses mostly on Easy Bikes as E3Ws in terms of structural specification and energy requirements because of their higher availability than Mishuk. E3Ws have a general shape with minor deviation in dimensions. Table 2 shows the structural specification of a typical E3W.

Table 2. E3W specification [50,51].

Specification	Value
Overall length (mm)	2850
Overall width (mm)	1080
Overall height (mm)	1850
Wheelbase (mm)	2200
Ground clearance (mm)	250
Climbing ability (degree)	20
Tire (front and rear)	4.0–12 tubeless
Net weight (excluding battery) (Kg)	320

4.2. Battery

E3Ws are battery-powered electric vehicles equipped with four to six batteries of different sizes with a capacity of 8–11 kWh, depending on the vehicle size that connects to the grid for charging [20,44]. Typical batteries used in electric vehicles are valved sealed lead acid (VRLA) batteries, LiFePO4, nickel-metal hydride batteries, etc. Valved sealed lead acid (VRLA) or lead acid batteries are commonly used for E3Ws worldwide because of cost constraints, availability, and safety [7,26]. Due to the availability of products from reputed manufacturers, lead acid batteries are mainly used for E3Ws, and over 1.9 million batteries are used annually in Bangladesh [14,20]. An E3W is typically powered by five 12-volt lead batteries, which consume around 11 kWh overnight charging [20,22]. These lead acid batteries are 180 AH (10.8 kWh) in capacity and are charged for around 8 to 10 h by the off-board battery charger either in the charging station or at home at night. In the case of newly purchased batteries, on a single charge, the vehicle can cover 140 to 150 km per day with a top speed of approximately 40 to 45 km/h [12,14]. In the majority of cases, the highest life span of the battery packs is 9 to 12 months [14,20]. Four of the five batteries are under the passenger seat, and one is under the driver seat, as shown in Figure 2.

(**a**) (**b**)

Figure 2. Lead acid battery pack location in E3W under (**a**) the passenger seat and (**b**) the driver seat.

4.3. Battery Charger

An E3W is charged by a battery charger, which is expected to be simple and reliable. There are two types of chargers available in the local market of Bangladesh such as copper transformers and aluminum transformers [20]. These chargers are equipped with a charge controller (also known as an electronic control unit (ECU) often used to avoid problems such as overcharging, waste of energy, environmental hazard, etc. [44]. Figure 3 shows two types of commercially available E3W chargers, 60 and 48 Volt, respectively, where the voltage labels are indicated on the front side of the chargers.

(**a**) (**b**)

Figure 3. Market-available Easy-Bike charger: (**a**) 60 Volt; (**b**) 48 Volt.

The E3W has battery pack capacities of 48, 60, and 72 Volts. Among them, 60 Volt is the most common. It is generally made of five 12-Volt batteries, commonly charged overnight around 10–12 h, and consumes an average of 8–11 kWh of electricity [15]. Generally, the three-wheeler off-board charger connects to a single-phase AC plug for slow nighttime charging. The charging time takes about 8 to 10 h, depending on the battery capacity and depth of discharge [12].

4.4. Motor

Induction motor, Brushless DC (BLDC) motor, Synchronous motor, and Switched Reluctance motor (SRM) are considered the main candidates for electric vehicles [26,52]. Permanent Magnet (PM) BLDC motor is widely used for E3W by manufacturers because of its availability, lower cost, high power density, high performance, compactness, and high efficiency [7,26]. In an E3W, the BLDC motor is accompanied by a motor controller. The motor controller uses Hall sensors to detect the rotor position and produce logic signals to operate the BLDC motor [53,54]. Such a control arrangement is simple and lowers the cost of the motor controller. Figure 4 shows a BLDC motor that uses in E3Ws.

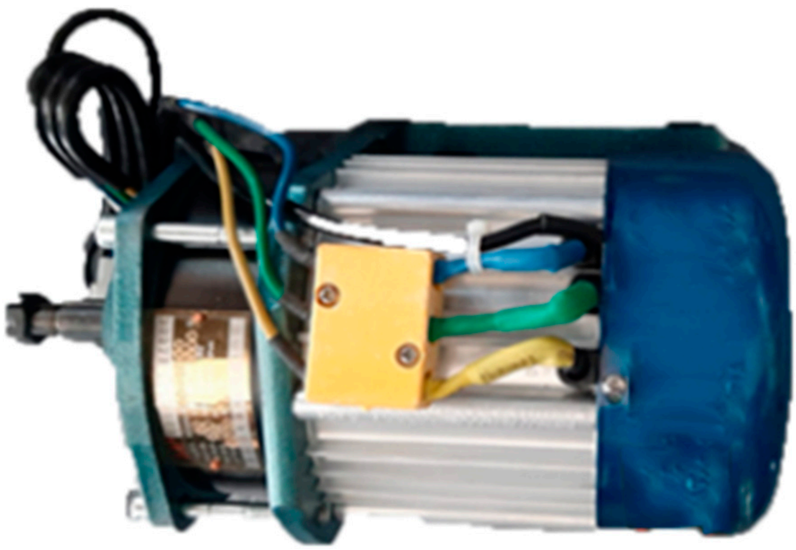

Figure 4. A brushless DC motor used in E3Ws.

The corresponding specifications of the BLDC motor are listed in Table 3.

Table 3. Specification of an E3W BLDC Motor [55,56].

Specification	Value
Rated power (W)	1000
Rated voltage (V)	60
No-load speed (RPM)	3800
Rated speed (RPM)	3420
Rated current (A)	22
No-load current (A)	5
Rated torque (NM)	3.9
Maximum efficiency (%)	≥84
Reduction ratio	1:5.44
Number of slots	12
Number of poles (magnets)	8

4.5. Charging Station

E3Ws mostly charge in a charging station, providing security and charging infrastructure [20]. As most homes in rural spaces lack sufficient space to store vehicles securely, charging stations provide a convenient solution. The charging process for E3Ws is off-board charging, where the battery charger is placed outside the vehicle. Figure 5 shows a charging station of E3W and charging arrangement in Bangladesh.

(**a**) (**b**)

Figure 5. E3W charging station: (**a**) parking arrangement; (**b**) E3W charging.

5. Methodology

In this work, the challenges of E3W are divided into two major categories: (1) technical challenges and (2) environmental challenges. Each category is subdivided into hierarchal classes based on potential impacts and priority. Challenges with higher priority levels require rapid response compared to those with a lower priority level. Possible solutions have been proposed to address those challenges accordingly, where a solution may mitigate more than one challenge and vice versa. Figure 6 shows the categorical priority system for the challenges and solutions considered here, where n and m are integer numbers.

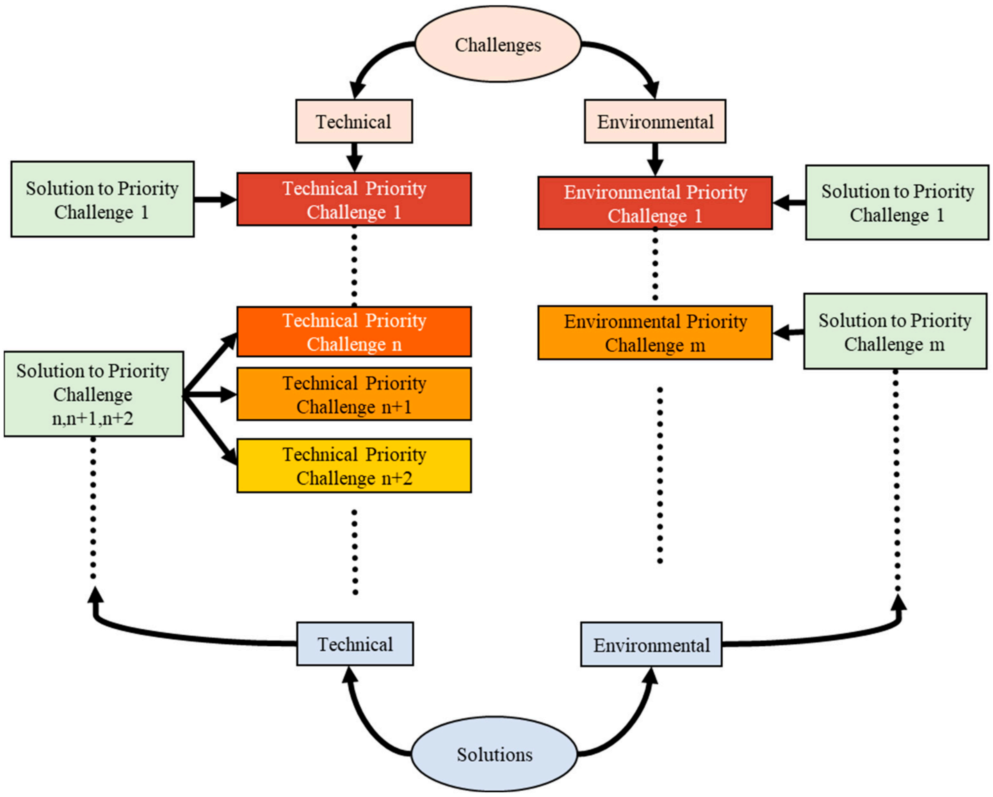

Figure 6. A categorical priority-based approach for E3W's challenges.

In this work, nine challenges of E3W were identified from the technical perspective, and two challenges were identified from the environmental perspective. Table 4 presents the distribution of challenges in priority classes and their potential solutions.

Table 4. E3W challenges classified into categories.

Challenges	Priority Class	Challenges
Technical	1	Structural Deficiency and Poor Braking System
		Safety Concerns
	2	Limited Range
		Battery Quality and Health Cycle
	3	Motor Quality
		Battery Charger
	4	Grid Integration
		Additional Power Supply
	5	Quality Products and Warranty
Environmental	1	Battery Disposal
	3	Indirect Emission of Greenhouse Gas

A thorough study of the challenges and their potential solution are presented in the sections "Challenges of Electric Three-Wheelers" and "Potential Solutions and Sustainability", respectively.

6. Challenges of Electric Three-Wheelers

Despite high popularity in rural, suburban and urban areas, there are many challenges for E3Ws to integrate with public transportation. These challenges are a significant barrier for E3Ws to have a sustainable transport, market, and employment scope. In this paper, the challenges are classified into technological and environmental aspects.

6.1. Technological Challenges

6.1.1. Structural Deficiency and Poor Braking System

The use of E3W is limited to low-speed applications for cheap transport because of the high propensity to roll over during cornering. The chassis of E3W is needed as a design to reduce structural weight and ensure safety. Therefore, a static and dynamic investigation is to be conducted in order to determine chassis strength rigidity [27]. The vehicle's safety directly correlates with the vehicle frame [57]. The frame must withstand loading, such as vehicle curb, payload, and driver weight, without deformed damage. As the stress in the frame cannot pass the yield strength of the frame material, the material selection is a significant part of the vehicle manufacturing process [58]. The current E3W structure is very light, unstable, and prone to topple [40]. The generated lateral forces can quickly turn them over due to their vulnerability to rollover [19]. This stability issue is dominant at high speeds [59]. Therefore, the usage of E3Ws is limited to low-speed transportation [60]. Being mostly locally assembled, it has severe drawbacks regarding braking and suspension systems. For example, the brake pads for the rear tires of E3Ws are driven by a simple mechanical pulley that sometimes needs to be fixed, especially when the vehicles are moving fast. The absence of safety ratings or safety setups in E3Ws risks the lives of the passengers [14].

6.1.2. Safety Concerns

In 2019, 8% of fatal accidents in Dhaka district were caused by E3Ws, which was 13% for the whole country. [61]. Driving these E3Ws under such substandard braking and suspension systems can have fatal consequences for the drivers as well [14]. In the absence of seat belts, occupants of an E3W can get thrown out of the vehicle, risking fatal head injuries [40]. Uncontrolled charging results in a gassing effect of mostly highly flammable hydrogen (H_2) gas, and unless proper ventilation is available at the charging place, explosions may take place [20]. Moreover, E3Ws are also being charged at home where there is no proper ventilation, which brings about the possibility of human casualties [62].

6.1.3. Limited Range

The vehicle speed depends on the battery charge. With a fully charged battery, an E3W can cover 90 to 150 km/day with a top speed of 40 to 45 km/h [12,14]. Moreover, the slope and inadequate conditions discharge the battery state of charge (SOC), rapidly reducing the driving range. In the evening and night, the auxiliary loads such as headlights draw additional energy from the batteries, further reducing the driving range. Conventional CNG and LPG-based three-wheelers include air-cooled two-stroke or four-stroke engines that can quickly fill their fuel tanks from available filling stations. However, overnighting 6–10 h of battery charging requires the E3W for a daylong operation. The E3W charging stations are very limited in number and have limited availability, such as CNG and LPG filling stations. These issues greatly limit the range of E3Ws.

6.1.4. Battery Quality and Health Cycle

The speed and driving range of the three-wheeler depends on the battery state of charge (SOC) [7,12]. As the vehicle covers distances, the battery's charge becomes reduced. Therefore, the battery capacity (in kWh) decides the range that can be covered by the vehicle with a single charge [7]. The primary objectives are to increase the driving range with a given battery and reduce the battery pack's degradation due to complex stresses in discharge currents [63]. The battery pack with higher capacity can undoubtedly increase the driving range, but it increases the vehicle's size, weight, and cost. Therefore, it is essential to select the battery capacity that would give an optimum solution of driving range versus the weight/cost of the E3W [7]. The lead acid battery is mainly used in conventional E3Ws.

The life cycle of lead acid batteries is considerably lower due to the high depth of discharge (DoD) value limiting the highest life span of the battery packs from 9 to 12 months [20]. In order to ensure the battery's good health, the state of charge (SOC) must stay above 40% to 50% [7,64]. Moreover, the majority of E3Ws are returned to the charging station being fully discharged with battery SOC as low as 5% after its day-long operation. This significantly reduces the battery life cycle [65] and results in frequent replacement of the battery pack contributing to operating costs for E3Ws [14]. Although li-ion batteries can provide a solution to these problems, these batteries are higher in cost compared to lead-acid batteries. Moreover, the recycling efficiency of Li-ion batteries is around 50%, while in the case of lead-acid batteries, it is greater than 95%. Therefore, Li-ion batteries have become more expensive than lead acid batteries in recycling [64].

The lead acid battery technology has also shown inherent limitations in power, speed, lifetime, and refueling [66]. In the case of a lead acid battery, O_2 gas forms at the positive electrode, and H_2 gas forms at the negative electrode after the battery is fully charged. The gas mixture forms a detonating gas that exhibits 4–72% explosiveness. Moreover, continuous overcharge results in water loss, electrode corrosion, and reduced battery life span [64]. Although the Li-ion battery system is relatively maintenance-free, there are concerns over battery overheating, combustion, and explosive disassembly in an uncontrolled charging scenario [8]. A battery management system (BMS) can be applied to tackle this issue, as it regulates the battery charging process [67]. Since there are many cells in a battery pack of an E3W, it requires heat management, cell state of charge monitoring, and current leakage detection so that battery safety and a prolonged lifetime can ensure.

6.1.5. Motor Quality

Besides the battery pack, the motor rating is one of the most significant parameters in deciding the cost and range of an E3W. E3Ws cover short-range driving cycles with motor requirements of high power density and torque, low speed starting torque, lightweight, low noise and vibration, high reliability, and low cost. Therefore, to properly select the motor for E3W, its performance, operating conditions, efficiency, economic feasibility, etc., must be considered [38]. An under-rated motor may not meet the required torque and power demand, while an overrated motor may result in low efficiency and high cost [26]. The commercially available motor for the E3W is the 1 kW permanent magnet brushless DC (PMBLDC) motor, and the motor controller allows for peak current flow of three to four times the rated current. Therefore, the motor can meet higher power demand than its rating accordingly. In suburban and city routes, the E3W has to run through significant acceleration and deceleration due to high traffic, and the motor power demand significantly increases during the vehicle's acceleration. Therefore, in most instances, the motor runs overloaded. Overloading results in overheating of the motor, and continuous overheating leads to demagnetizing the permanent magnet [68]. Therefore, the E3W motor suffers from a limited lifetime, and it is needed to be changed frequently to keep the E3W operational. Although BLDC motor drive is simple and the motor controller is comparatively inexpensive versus other types of motor, such arrangements result in a high torque ripple in a BLDC motor [54].

6.1.6. Battery Charger

The charger, along with its controller, consists of power electronic components [20,44] such as different types of transistors such as metal oxide field effect transistors (MOSFET) and insulated gate bipolar transistors (IGBT), capacitors, and other electronic equipment [7,44]. When the charger and controller operate, the equipment generates heat, causing the temperature of the equipment to rise, and the charger and controller lifetime can decrease with increased temperature [69]. E3W chargers include a rectifier/inverter circuit that produces harmonic contamination to the electric grid [67].

6.1.7. Grid Integration and Power Quality

The electricity required for charging E3Ws is mainly drawn from the power grid. As thousands of electric vehicles are being integrated with power systems, there are likely to have a negative impact on the grid [67]. E3Ws are usually connected overnight and require a large amount of electrical power to charge [16].

The utility energy sector in Bangladesh has one national grid with an installed capacity of 20,383 MW (268 MW renewable power) as of the 2019–20 fiscal year. The total energy generation in the fiscal year 2019–2020 was 71,419 GWh as of June 2020 [70]. An approximate consumption comparison of the charging with the total generation of Bangladesh demonstrates in Table 5.

Table 5. E3W energy consumption comparison.

Details (as of 2020)		Energy in Giga Units (1 Unit = 1 kWh)
Total Energy Generation in Bangladesh in one year		71,419
Total Energy Generation in Bangladesh in one day	365 days	195.66
Number of E3W approximated	1 million	
Average energy consumed by one E3W	11 units	
Number of average units consumed by all E3Ws		11

During off-peak hours, a large number of E3Ws are integrated with the grid for charging purposes. Table 4 shows that about 11 GWh of energy is used by E3Ws, which is around 6% of the daily energy generation. These vehicles are usually charged overnight and are likely to have a negative effect, as a significant amount of power is consumed in the charging process [20]. It has been observed in the Bangladesh power system that the timing peak load has shifted from 7:00 PM to 10:00 PM over the years [15,71], as shown in Figure 7.

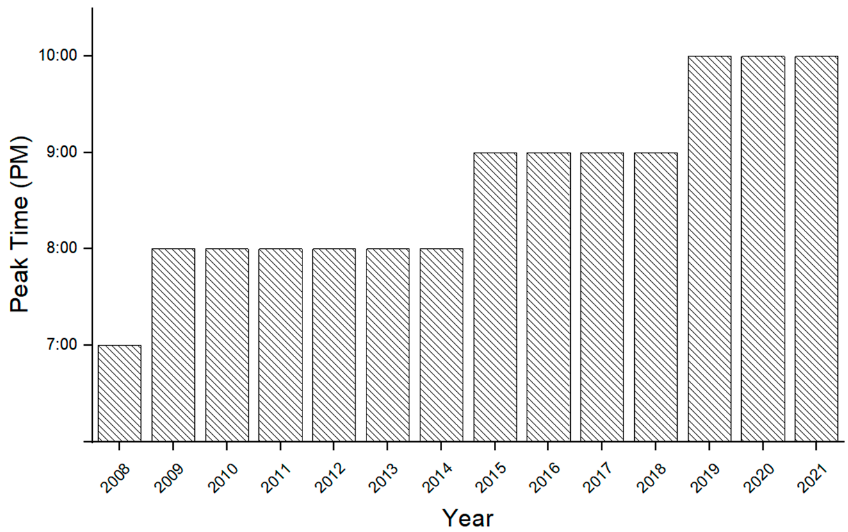

Figure 7. Peak generation time shifting (after [15]).

Although there are many reasons for the increase in peak load, an increase in E3Ws connected to the grid for charging is one of the main reasons to be considered for raising peak load [20]. As of 2008, E3Ws first started their commercial journey; thus, there was a minimal number of these vehicles compared to the present. Over the years, the number of E3Ws has been increasing; therefore, a significant amount of charging load is being integrated with the grid. Moreover, during charging, these vehicles are connected to the grid as an active load in an uncontrolled way, and no specific protocols are maintained.

Accommodating charging facilities for a growing number of E3Ws, and an upgrade in the distribution network, including distribution lines and cables, transformers, and feeders, is required to ensure harmonic injections, phase imbalance, etc., undesirable phenomena are within control [31]. The charger is a single-phase charger and consists of an AC/DC converter connected randomly to the power system while charging. The AC to DC conversion in the E3W charger injects harmonics into the distribution system and reduces the device's power factor, resulting in the charger's heating. The total harmonic distortion of current varies throughout the charging time of the battery. Higher THD results in higher heating and core loss [67]. Due to the low-quality power supply, charging costs also increase. Moreover, charging E3Ws in a considerable density in closed proximity may cause a dip in power [31]. Therefore, with the increase in the use of E3Ws and mass penetration in the market, there has been a rising concern over the effect of charging on the electrical grid of Bangladesh.

6.1.8. Additional Power Supply

With the increasing number of E3Ws, the electricity demand for charging is also increasing. Therefore, distribution companies may need to increase the substation capacity to meet the electricity demand when E3Ws are charged simultaneously [7]. However, if the electricity grid fails to accommodate E3W charging, distribution generators such as diesel generators may be used to cover up this additional charging load. Additional financial investment is required to install such alternative generation sources. Moreover, such an arrangement would further couple the transport sector with fossil fuels, likely leading to more GHG emissions [72].

6.1.9. Quality Products Availability and Warranty

Due to the absence of regulations, local market vendors and customers face problems, especially with batteries. Warranty is not offered for most battery packs due to inefficient charging systems [20]. Moreover, E3Ws are accident-prone due to substandard mechanical braking and suspension system. Thus, there is a requirement for significant expenditure for repairing purposes. Moreover, higher battery capacity and higher-rated motors are required to increase the driving range, further increasing the cost.

6.2. Environmental Challenges

6.2.1. Battery Disposal

Lead-acid batteries are mostly used in E3Ws due to availability and lower cost [73]. However, the disposal of these lead acid batteries can be of great concern because of their potentially hazardous effect on public health [20]. Lead acid batteries contain lead and sulfuric acid solution, where lead is a highly toxic material, and sulfuric acid is a corrosive electrolyte. Disposal of lead acid batteries in solid waste landfills causes lead and sulfuric acid to bleed into the soil, contaminating crops, vegetables, and groundwater [8,64]. Moreover, batteries disposed of near rivers, streams, lakes, or coastal water can threaten aquatic life [64]. Some E3Ws are charged at home, but excessive gassing due to battery overcharging makes it inconvenient and unhygienic [20].

Li-ion batteries contain copper and aluminum, which are used as current conductors, and $LiCoO_2$ is used as the cathode material. Although they are not as toxic as lead-acid batteries, excessive levels of cobalt and copper can cause hazardous environmental effects. Recycling can contribute to minimizing such threats; therefore, recycling facilities should be established and modernized [64]. Moreover, in the case of solar energy charging stations [23,74], specific regulations should be maintained to dispose of large solar e-wastes [75].

6.2.2. Indirect Emission of Greenhouse Gas

Electric vehicles are inherently free of tailpipe emissions. However, the energy required to charge electric vehicles is generated from power plants that run on fossil fuels.

Greenhouse gases are produced by different steps of electrical energy generation, such as the construction, operation, and decommissioning of power plants [5]. The greenhouse effect has many adverse environmental effects, including global warming, ocean acidification, air pollution, ozone depletion, etc. [76].

7. Potential Solutions and Sustainability

The challenges of E3Ws are the major concerns for the people and the government. However, the potential of these vehicles as a mode of environmentally friendly transport cannot be ignored. The challenges can be tackled with a proper combination of technological, financial, and environmentally friendly efforts. This section presents some solutions that can overcome the technological, financial, and environmental challenges faced by E3Ws in Bangladesh.

7.1. Technological Solutions

7.1.1. Strong Vehicular Frame with Updated Braking and Suspension System

Lightweight vehicle frames reduce power consumption. Therefore, mild steel material can be in the frame [11]. The conventional E3Ws have severe problems with braking and suspension systems [14]. Building a proper structure in the alpha framework is a potential solution to these problems. The Alpha frame is the earliest basic frame design of E3Ws, and Alpha-0, Alpha-1, and Alpha-2 are the upgraded designs, as shown in Figure 8 [27].

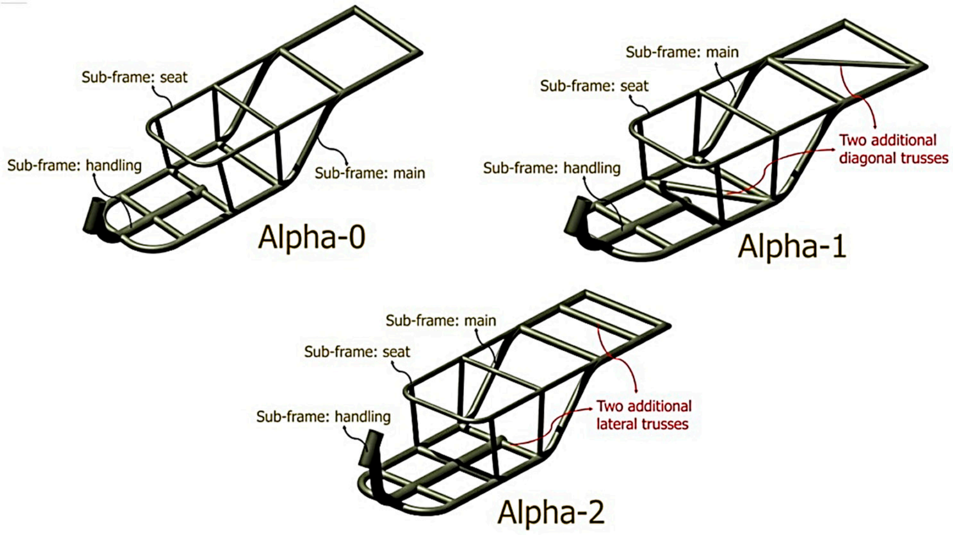

Figure 8. Alpha frames for E3W [27].

Alpha-2 frame has the best deformation performance, providing vital support to withstand the loading and distribute the stress to prevent vehicle deflection when loading is applied [27]. Alpha frames have three main parts: the main frame, the seat frame, and the handling frame. The main frame is where other components such as a cargo box, suspension system, driver compartment, and upper structure are installed. It bears the main loading through the joint between components. The seat frame is the sub-frame that receives the main loading from the driver's weight and provides comfort to the driver during the vehicle operation. The handling frame associates the steering system with the revolved bearing joint. Fix displacement is applied in the handling joint to prevent the frame from moving [27]. A tilt control system can be applied in the three-wheeler control as tilting an E3W in the opposite direction to that of the lateral acceleration can reduce the severity of rollover to a large extent ensuring safety and excellent maneuverability [19]. Active tilt control system (ATC), steering tilt control (STC), direct tilt control (DTC), etc., are among the tilt control systems that can improve the E3W maneuverability and actuate the vehicle to the desired tilt angle during the drive [60]. A developed vehicle structure and braking system will minimize the risk of accidents and ensure passenger safety.

7.1.2. Charging Facilities and Battery Swapping Method

The readily available CNG petrol pump stations should be integrated with E3W charging facilities to increase the availability of charging points [77]. The battery swapping process can extend the range of E3Ws where the discharged batteries would be swapped with the fully charged batteries [59]. This method will help to preserve the battery life by enabling the swap of batteries before complete discharge. The overall battery-swapping process should be efficient and effective, and the service providers must be well trained [23]. These facilities can minimize the anxiety of limited driving range for E3Ws [78]. The availability of charging stations at frequent distances can reduce battery storage demand for E3Ws, reducing the overall vehicle cost. In addition, charging batteries with high currents can result in lower effective battery demands [9].

7.1.3. Replacing Lead Acid Batteries with Li-ion batteries

The vehicle speed depends significantly on battery charge and health condition [12,26]. With the advent of innovation in lithium-ion battery technology for EVs, the latest vehicle designs are based on the Li-ion battery pack [7]. This design consideration has already accelerated the shifting of E3W battery technology from lead-acid to Li-ion technology [8]. Li-ion-based electric vehicles, along with their superior compactness and increased life cycle, have a higher energy density, weight density, faster recharge time, and longer replacement time frame than conventional lead acid (Pb-acid) battery technology [8,26,79,80]. Where a lead acid battery can take up to 12–16 h to become fully charged, Li-ion batteries ($LiFeSO_4$) take 2–3 h to be fully charged [64]. Li-ion batteries have a three to four times higher life cycle compared to lead acid battery, and comparing the life cycle, it can be said that the Li-ion battery is 2.5 times lower in size than lead acid batteries [64]. Table 6 shows the comparison of lead acid battery and Li-ion battery characteristics for E3Ws.

Table 6. Comparison of lead acid battery and Li-ion battery characteristics [31,73].

Characteristics	Lead Acid Battery	Li-ion Battery
Nominal Voltage (Volt)	2	3.6
Energy Density (Wh/L)	35	118–250
Specific Energy (Wh/kg)	30–50	120–140
Specific Power (W/Kg)	180	200–430
Operating Temperature (C)	−15 to 50	−20 to 60
Life Cycle	1000	2000
Production Cost (USD/kWh)	60	150

Li-ion batteries have higher specific energy, energy density, good efficiency, low weight and self-discharge, no memory effect, and long life compared to that of lead acid batteries [73]. Li-ion battery technology requires a higher initial cost than lead acid batteries, but the overall payback period would be lower. Moreover, the torque and power demanded by Li-ion batteries are approximately 40% lower than those demanded by a lead acid battery-based E3W [26]. Batteries with high power/energy characteristics can have a high cost [81], but regular usage of battery storage in the electric vehicle makes such battery systems economically feasible [82]. Moreover, Li-ion battery elements are less hazardous than lead; thus, environmental pollution through battery disposal can be minimized [64].

The trend of adopting Li-ion batteries has already started as new E3W equipped with Li-ion batteries are in line to be launched soon [83]. Figure 9 shows two types of Li-ion battery cells that are used as E3W and the battery pack frame.

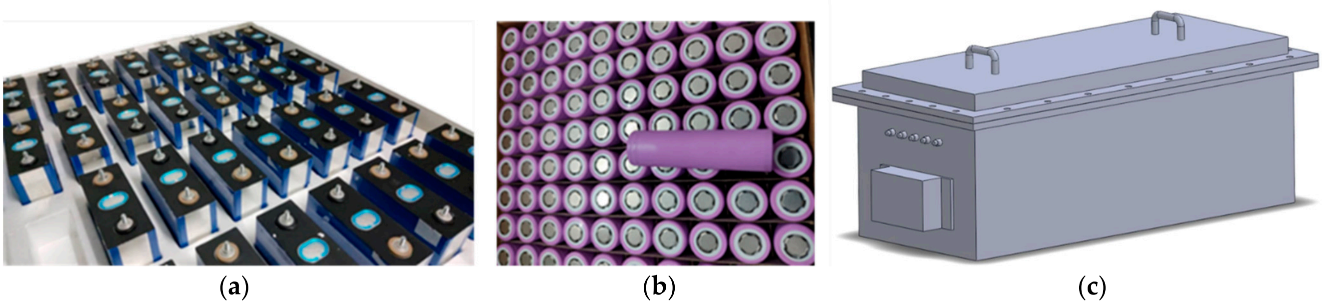

Figure 9. Li-ion battery cell: (**a**) prismatic type; (**b**) cylindrical type; (**c**) battery pack frame.

However, unlike lead acid batteries, Li-ion batteries are more susceptible to damage and explosion in case of overcharge [52]. A battery management system (BMS) is used to regulate the charging process and prevent the overcharging phenomenon.

The battery pack is usually fixed on the frame together with module cases, wiring, and a BMS system to ensure its safety from external shock, heat, and vibration [84] and to prevent mechanical deformation [85]. With the E3W structure, the battery pack is to be placed under the passenger seat. Therefore, the battery pack is more likely to remain undamaged for forward collision between E3W and similar vehicles or cars. As an E3W is a slower vehicle, it is mainly operated on suburban and village roads as well as in some part of the cities in Bangladesh where fast-running vehicles are less active. Moreover, the battery pack will have two layers of protection—the battery pack frame and the passenger seat box frame. Therefore, unless an E3W experiences a heavy back collision from other vehicles, the Li-ion battery pack is expected to be structurally unharmed from fire in a vehicle collision.

7.1.4. Efficient Motor and Regenerative Braking System

The electric motor and motor controller each have their own efficient and relatively inefficient regions of operation, and optimizing their operation to correspond to a particular driving pattern would result in better vehicle range [86]. The motor in E3Ws should be selected to satisfy both continuous and peak power and torque demand while operating within thermal limits and financial constraints. Higher efficient motors can result in lower electricity consumption [72]. With minimization overloading, the motor with higher power ratings can be utilized.

A suitable candidate for replacing the BLDC motor is the permanent magnet synchronous motor (PMSM). Along with high efficiency, high-power density PMSM can generate constant torque with lower torque ripple than a BLDC motor [52]. However, PMSM requires a comparatively complex and expensive motor controller. Using rare Earth permanent magnets results in a higher cost to the BLDC and PMSM motor. The switched reluctance motor operates without permanent magnets and is simple in construction [87]. Despite high faulting tolerance and low cost, SRM suffers from high torque ripple and comparatively lower efficiency [52,88,89]. Each type of motor has its merits and demerits. Therefore, proper motor type selection must be made considering performance requirements and financial constraints.

A geared motor with less torque and higher speed is more efficient than a direct drive motor with high torque and low speed. The size of the geared motor is also smaller than that of the direct drive motor due to the lower requirement of rated torque [26,38]. A regenerative braking system can be added to the vehicle controller, as whenever the E3W speed is reduced or goes on a downward slope, the vehicle's kinetic energy is converted into electrical energy, which would charge the battery system [7]. Regenerative braking can increase the vehicle's range and reduce the required battery pack size. However, such a system will incur additional control and increase the cost.

7.1.5. Demand-Side Management

Demand-side management is a type of load management that involves changing the energy use habits of consumers, which can be adapted to shift the pattern of connecting E3Ws to the grid from peak hour to off-peak hour. Therefore, no vehicle can be connected and charged during peak hours [20]. If authority exercises the demand-side management, the peak load can be shaved for better capacity utilization of the power grid. In this way, the owners of E3Ws would be compelled to charge the vehicle during off-peak hours. A timer circuit mechanism can be implemented in the charging station so that E3Ws can only charge after 10 PM and before 5 PM [20]. The charging process can be regulated, and excess pressure on the power grid due to E3W charging can be averted with such measurement.

7.1.6. Establishing the Automobile Manufacturing Industry and Market

With the rapid growth of E3Ws, there is excellent potential to develop a manufacturing industry and associated equipment markets. The standardization of parts and equipment of E3Ws can help grow the market and lead to innovation, design changes, and technology upgrading toward higher-quality products locally and globally. Increasing production volume due to many different assemblers with proper supply would lower the cost of E3W manufacturing and related accessories. Standardization enables the production of easily interchangeable components between models and manufacturers, giving assemblers and suppliers more freedom in their choices for partners and facilitating a more open industry structure [8]. Business model innovation can dismantle the barriers to accelerate the diffusion of sustainable technologies [82]. Since rural and suburban areas are the most promising ones for E3Ws, local markets can be developed to create employability for many people. At present, Beevatech and Dynamic AV are the most renowned local E3W manufacturers in Bangladesh [48].

7.1.7. Lowering the Cost of Equipment

The E3W is suitable for low-cost and sustainable transport because of its lower initial cost, less maintenance, small size, and better maneuverability than four-wheeled vehicles [19]. New vehicle designs would further reduce the initial cost and improve performance [90]. Moreover, enabling custom-duty exemption on battery cells would lower the cost of batteries for E3Ws. With the initial cost lowering, the sales of E3Ws would increase [90]. In implementing such environmentally friendly sustainable transport technology, the main aim should be to ensure the cost advantage of sustainable solutions over conventional ones, which is affected by the volatility of environmental factors such as electricity prices, feed-in remunerations, and fuel prices [82]. These steps will draw CNG-LPG-run three-wheeler drivers and passengers to E3Ws and accelerate the adoption of E3W in public transportation.

7.2. Environmental Solution

7.2.1. Battery Recycling

Battery recycling can undoubtedly minimize the pollution from improper battery disposal. The lead acid batteries in E3W have a high recycling rate and are easily recyclable [52]. Bangladesh mainly imports batteries from China. Companies such as Rahim Afrooz, Panna Battery, and HAMKO have only independent recycling facilities for lead-acid batteries. The recycling process also results in lower net battery costs. A Li-ion battery recycling facility is currently unavailable in Bangladesh [64].

7.2.2. Incorporation of Renewable Energy in the Charging Process

Renewable energy-based charging stations can greatly support the grid system for charging a large number of E3Ws. Solar and wind energy technology can be incorporated to meet the electricity demand for charging along with the grid [5,82] and increase the engagement of renewable energy in power generation [23]. Charging of E3Ws with renewable energy sources can further reduce emissions [74]. Being a tropical climate country, Bangladesh receives abundant sunlight around the year. The average sunny hours per day are 6.5, and the annual mean solar radiation is 0.2 kW/m^2 and 4–5 kWh/m^2/day in about 94% of Bangladesh [91]. Figure 10 shows the monthly average solar radiation in Bangladesh.

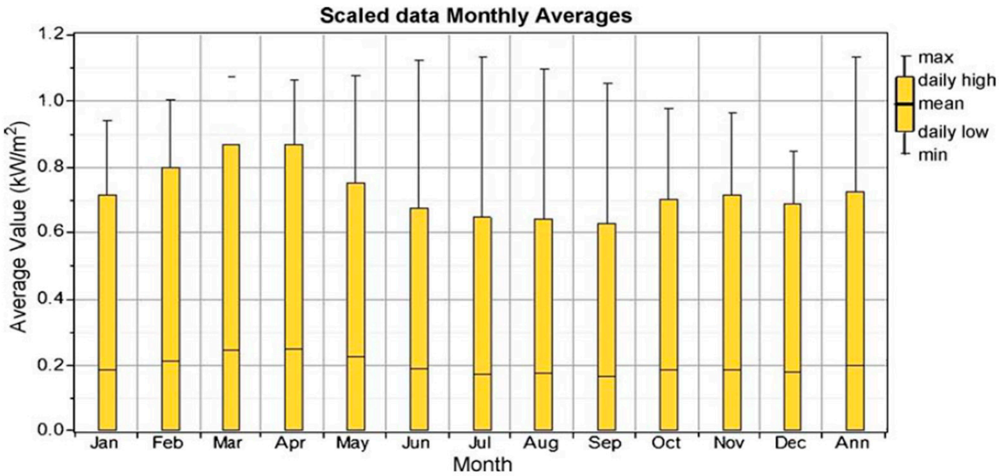

Figure 10. Monthly average solar radiation in Bangladesh. Reproduced with permission from Ref [91]. Mondal, M.A.H.; Denich, M. Renewable and Sustainable Energy Reviews; published by Elsevier, 2010.

In Bangladesh, various organizations such as the Sustainable and Renewable Energy Development Authority (SREDA) and Infrastructure Development Company Limited (IDCOL) are working for sustainable infrastructure development to fulfill the vision of meeting 10% of the electricity demand using RES (mostly solar) by 2030 and reducing 20% of electricity consumption through conservation [92,93]. The utilization of solar energy in charging E3Ws would reduce pressure on the grid and GHG emissions [5]. The output power of a photovoltaic (PV) system is directly dependent on the solar irradiation profile. Battery storage can be used as a compensating reservoir to balance the generated electricity and electric vehicle charging load. Battery storage will allow for the decoupling of solar energy supply and demand [82]. Net-metering systems can be introduced in PV charging stations where the solar PV energy produced during the day time is supplied to the national grid, and during off-peak hours, E3Ws would be charged from the grid. As such a system eliminates the requirement of charging batteries with solar energy, the investment is reduced significantly, and the system can operate without subsidy; hence, such a system would also be economical [5,74]. The layout of the net metering-based E3W charging station is shown in Figure 11.

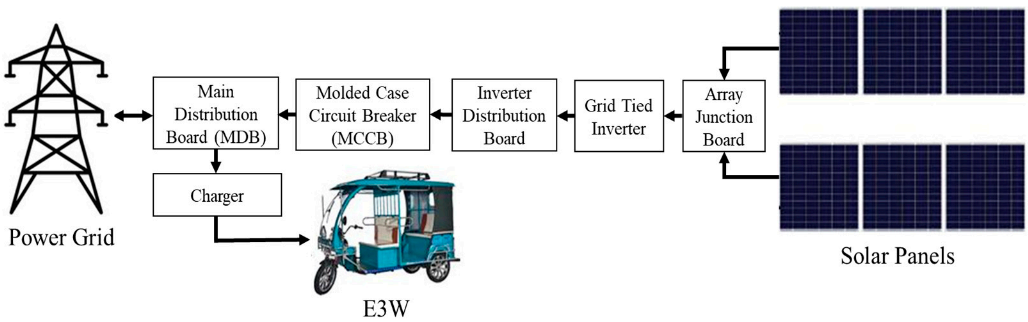

Figure 11. Net metering based electric three-wheeler charging station.

Installing PV panels on the roof of the E3W can further integrate renewable energy with the transportation sector. In such an arrangement, the PV panel would be able to provide a continuous trickle charge to the battery to maintain the state of charge of the battery while the vehicle is driving [5,12]. The charge-sustaining capability enables faster acceleration, cruising capability, enhanced range, and higher battery lifespan [12]. Moreover, the roof-covering solar panels can supply the auxiliary load of the vehicle, such as a fan, light, etc., which is estimated to be 0.5 kWh per day [23]. Along with solar PV energy, wind energy can be incorporated into the charging process in some areas, particularly coastal regions. In Bangladesh, the monthly average wind speed at the height of 20 m is 3.55 m/s throughout the coastal areas of Cox's Bazar [5]. Ensuring renewable energy availability for E3W charging can reduce the dependency on additional distribution energy sources such as diesel generators. Thus, policy should be devised to utilize such renewable sources in this transportation sector [94].

8. Current Policies and Recommendations

Due to low fare and noiseless operation, E3Ws have been gaining popularity among people, especially in suburban, rural, and outside metropolitan cities [49]. Two major concerns are associated with E3Ws' fitness and electricity demand. The Bangladesh Road Transport Authority (BRTA) has drafted guidelines on electric vehicles with a particular focus on E3Ws for making regulations, fitness certificates, and tax tokens mandatory [95]. With the increasing demand and usage of E3Ws, battery charging points started being established at different corners of the cities, most of which do not have legal electricity connections to regulate the charging process. Bangladesh Energy Regulatory Commission (BERC) proposed a 0.09 USD or 90 cents tariff against the consumption per unit of electricity for charging these vehicles only in a garage or charging stations, and the service charge was proposed at 29 cents for a one-phase line and 47 cents for a three-phase line in 2007 [96]. The Bangladesh Energy and Power Research Council (BEPRC) is formulating guidelines for E3Ws [97].

In July 2022, the Sustainable and Renewable Energy Development Authority (SREDA) under the Ministry of Energy and Mineral Resource, Government of the People's Republic of Bangladesh, formulated some guidelines for the electric vehicle charging infrastructure [98]. These guidelines are more conspicuous for E3Ws since they are the major share of EVs in Bangladesh. These guidelines include international standards and instructions on overload prevention, uncontrolled reverse current prevention, power unbalance prevention, vehicle parking spot, charging point positions, etc. Some international standards that must be followed in accordance with the guidelines are listed in Table 7.

Table 7. International standards for electric vehicle charging.

Schemes	Standard
Electrical Vehicle Conductive Charging System	IEC 61851-1:2017 [99], IEC 61851-23:2014 [100], IEC 61851-24:2014 [101]
Conductive Power Transfer	ISO 17409:2020 [102]
Over Current Protective Device	IEC 60947-2 [103], IEC 60947-6-2 [104], IEC 60269 [105]
Earthing	IEC 60364 [105]
Thundering Protection	IEC 62305 [106]
Insulation Of Charging Equipment	IEC 61851-1 [99]
Charging Cable	IEC 62893-1 [107]
Charging Station Equipment Protection	IEC 60529 [108]

The Electric Vehicle Registration and Operation Guidelines are being prepared by the Bangladesh Road Transport Authority (BRTA) [109–111]. The draft guidelines emphasize ensuring safety standards, fees, and an adequate economic lifetime for electric vehicles [110]. According to the draft electric vehicle guidelines, the registration, fitness checking, and route permit processes of electric vehicles will be as same as the engine-run motor vehicles. It states that the speed of electric vehicles in loaded conditions must be set to levels similar to conventional vehicles as per law. In addition, a vehicle's chassis must be engraved with specific details, such as its international vehicle identification number [109–111]. According to the draft guidelines, the lifespan of electric three-wheelers is 10 years, whereas for electric motorbikes is 12 years and for buses, trucks, cars, and pickups is 20 years [111].

Some recommendations has been presented to facilitate the integration of E3Ws, which are compliant with the Drafted Automobile Industry Development Policy 2020 by the Ministry of Industries, Government of the People's Republic of Bangladesh [112].

8.1. Development of Vehicle Structure and Braking System

As conventional E3Ws lack proper braking and suspension systems, technological involvement and standard manufacturing must mitigate these problems. Some potential solutions have been discussed earlier in this work.

8.2. Movement Restriction

The major accidents by E3Ws happen mainly on the high road. Although restriction laws have been imposed on E3Ws on the high road, the drivers do not follow the law and cause accidents frequently. Therefore, restriction laws must be followed strictly. Moreover, the number of E3W needs to be regularized to avoid traffic congestion.

8.3. Regulation on Vehicle Charging Process

As many illegal charging points have been established to support the large number of E3Ws, charging stations with proper regulations should be established in parallel with removing these illegal charging points. The proper tariff should impose so that the government can benefit while keeping the fare affordable and driving these vehicles profitable. Demand-side management can ensure that the charging would not impose negative pressure on the power grid.

8.4. Development of the Automobile Market

E3Ws manufacturing and assembling can be a potential market to produce high-quality, affordable vehicles. Priority should be given to local manufacturers/assemblers in the public procurement of automotive products and accessories. Government collaboration with the local components manufacturers would result in the generation of a list of products that can be manufactured locally for use in vehicle assembly and after-sales. Supporting the capacity building of component manufacturers to produce local content that meets quality standards will certainly facilitate investors from home and abroad to invest in this sector and establish manufacturing and ancillary plants. Moreover, buyers of locally assembled /manufactured E3Ws should be given a percentage of income tax relief to the value of purchase. Moreover, the manufacturers should concentrate on increasing local value addition. Lithium recycling facility installation can be considered a potential business opportunity [59].

8.5. Battery Import and Recycling

The government can announce customs duty exemption on battery cells such as lead-acid and Li-ion cells, which would lower the cost of batteries, making E3Ws the most economical mode of transport [7]. Moreover, a Li-ion battery recycling facility should be established to promote these batteries' usage in E3Ws.

8.6. Employment Issues

The government should impose incentives and regulations to train drivers of E3Ws to ensure these vehicles' standards and safe driving. Such steps can generate employment for poor and unskilled individuals [40]. The CNG-based three-wheeler drivers can be motivated through incentives to shift toward E3Ws. The government and private sectors can develop schemes to distribute E3Ws to the poor and unemployed to alleviate poverty [7].

9. Direction for Future Research

With the increasing number of E3Ws, there will be concerns regarding vehicle drivetrain components, charging process, consumer adaptability, government intervention, etc. As E3Ws are pursued as a mode of public transportation in some developing and under-developing countries, it is time to set a direction for research. Bangladesh imports the drivetrain components mainly from China. To properly assess the performance of drivetrain components such as electric motors, the real-time driving patterns in different regions of Bangladesh and other countries, optimizing drivetrain components according to specific regional requirements will likely result in higher system efficiency.

Moreover, driving patterns in different regions reflect the vehicle acceleration, velocity, and motor torque profile [113] and socio-economic characteristics of that region [38]. A vigorous study on the E3W driving pattern can provide helpful insight into drivetrain component optimum design and estimate consumer demand for E3Ws. Lead acid battery recyclability has already been explored. However, adopting Li-ion batteries calls for research on the recyclability of these batteries. Development of fast-charging infrastructure for E3Ws in the Bangladesh perspective requires attention to the limited space and financial constraints. The concept of refitting can be explored where the electric drivetrain replaces the fossil fuel-based drivetrain components from the CNG-LPG-run E3Ws while having the same or modified vehicle structure. This structure will reduce manufacturing costs and result in a shift toward E3W from their CNG-LPG counterparts. The velocity profiles of other vehicles also need to be considered to increase the number of E3Ws in city drive cycles. The feasibility of separate lanes for comparatively slow-moving vehicles such as E3Ws or route specifications can also be a prospective research area.

10. Conclusions

Although electric vehicles are not new, there has become a great need for sustainable and clean transport. However, people's perceptions, economic feasibility, social adaptation, and transport policies are still under examination for clean technologies and sustainability. The E3W potential of being an environmentally friendly form of comfortable public transportation is likely to be challenged by the technical deficiencies and some environmental issues associated with the vehicles. From the comprehensive review, the following points can summarize:

- The popularity of E3Ws is mostly attributed to their emission-free, noiseless operation and low and reasonable fare in short-distance travel and intra-city transportation.
- E3W can significantly contribute to lowering the country's dependency on fossil fuels for the transportation sector.
- In order to ensure safe and convenient transport, proper structural design with reliable braking and suspension systems is very important and must be standard for the E3W.
- Inherent problems such as limited range inhibit the E3W from meeting the travel demand.
- New and existing technologies must be incorporated to tackle various challenges of the E3W vehicles.
- The concerns related to battery disposal must be dealt with in a proper technical manner to fulfill the promise of pollution-free transport.
- Government and non-government organizations should adopt a collaborative approach to adopt E3Ws as sustainable transport.
- Bangladesh should align with this vision and adopt an environmentally friendly transport policy, as the world is adopting electric vehicles as future transportation.

Author Contributions: Conceptualization, M.J.A.H., M.Z.H., M.H, M.Z.R.K. and M.A.H.; Resources, M.J.A.H. and M.Z.H.; Supervision, M.H. and M.Z.R.K.; Visualization, M.H. and M.A.H.; Original Draft Preparation: M.J.A.H., M.Z.H. and M.H., Writing—Review and Editing, M.H., M.Z.R.K. and M.A.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. IQAir. *World Air Quality Report 2021—Region & City PM2.5 Ranking*; IQAir: Goldach, Switzerland, 2021.
2. Hossain, I.; Rahman, M.S.; Sattar, S.; Haque, M.; Mullick, A.R.; Siraj, S.; Sultana, N.; Ahsan-Uz-Zaman, M.; Samima, I.S.; Haidar, A.; et al. Environmental overview of air quality index (AQI) in Bangladesh: Characteristics and challenges in present era. *Int. J. Res. Eng. Sci. Manag.* **2021**, *4*, 110–115.
3. Chowdhury, H.; Chowdhury, T.; Rashedi, A.; Banik, S.C.; Khanam, T.; Saidur, R.; Sait, S.M.; Rosen, M.A. Energy and exergy assessment with updated Reistad estimates: A case study in the transportation sector of Bangladesh. *Energy Sci. Eng.* **2021**, *9*, 1349–1358. [CrossRef]
4. Cunanan, C.; Tran, M.-K.; Lee, Y.; Kwok, S.; Leung, V.; Fowler, M. A review of heavy-duty vehicle powertrain technologies: Diesel engine vehicles, battery electric vehicles, and hydrogen fuel cell electric vehicles. *Clean Technol.* **2021**, *3*, 474–489. [CrossRef]
5. Saleque, A.M.; Khan, A.M.A.; Khan, S.H.; Hoque, S. Drivetrain design and feasibility analysis of electric three-wheeler powered by renewable energy sources. In Proceedings of the 4th International Conference on Advances in Electrical Engineering (ICAEE), Dhaka, Bangladesh, 28–30 September 2017; pp. 432–438. [CrossRef]
6. Rana, M.S.; Hossain, F.; Roy, S.S.; Mitra, S.K. Energy consumption by battery operated autorickshaws. *Daffodil Int. Univ. J. Sci. Technol.* **2013**, *8*, 71–76.
7. Saxena, S.N. Two- and three-wheeler electric vehicles in India—Outlook 2019. *Int. J. Electr. Eng. Technol.* **2019**, *9*, 13.
8. Weinert, J.; Ogden, J.; Sperling, D.; Burke, A. The future of electric two-wheelers and electric vehicles in China. *Energy Policy* **2008**, *36*, 2544–2555. [CrossRef]
9. Hanke, B.; Goletz, M.; Wachter, C.; Kühnel, M.; Ehebrecht, D.; Rinderknecht, F.; Nickel, B.; Lenz, B.; Tolk, D.; von Maydell, K.; et al. Interdependence of charging infrastructure and battery demand of light electric 3-wheel motor taxis. In Proceedings of the Fifteenth International Conference on Ecological Vehicles and Renewable Energies (EVER), Monte-Carlo, Monaco, 10–12 September 2020.
10. Le, H.; Yang, Z. *Market Analysis of Two- and Three-Wheeler Vehicles in Key ASEAN Member States*; International Council on Clean Transportation: Washington, DC, USA, 2022.
11. Arifurrahman, F.; Indrawanto; Budiman, B.A.; Santosa, S.P. Static analysis of an electric three-wheel vehicle. In Proceedings of the 5th International Conference on Electric Vehicular Technology (ICEVT), Surakarta, Indonesia, 30–31 October 2018; pp. 218–223. [CrossRef]
12. Shaha, N.; Uddin, B. Hybrid energy assisted electric auto rickshaw three wheeler. In Proceedings of the International Conference on Electrical Information and Communication Technology (EICT), Khulna, Bangladesh, 13–15 February 2014; pp. 1–6. [CrossRef]
13. Saxena, S.N. Revolution in growth of three-wheeler electric vehicles in India: Providing job opportunities to semi-skilled and unskilled people. *J. Glob. Tour. Res.* **2019**, *4*, 117–126. [CrossRef]
14. Khan, Z.R. *Final Report on the Efficient Charging System for Electric Three Wheeler*; REEP, GIZ: Dhaka, Bangladesh, 2018.
15. Awal, M.R.; Rahman, M.M.; Islam, A.K.M.N.; Hossain, J.A.; Khan, M.Z.R. Energy consumption analysis of electric three wheelers in Bangladesh. In Proceedings of the IEEE International Conference on Power, Electrical, and Electronics and Industrial Applications (PEEIACON), Dhaka, Bangladesh, 29 November–1 December 2019; pp. 35–38. [CrossRef]
16. Rian, M.Z.; Rahman, A.N.M.M. Study on power consumption and social aspects of battery operated auto-rickshaw. In Proceedings of the International Conference on Mechanical, Industrial and Energy Engineering, Khulna, Bangladesh, 26–27 December 2014.
17. Centre for Rehabilitation of the Paralysed. Easy Bike Accidents Increase Physical Disability: CRP. Available online: http://www.newagebd.net/article/4230/easy-bike-accidents-increase-physical-disability-crp (accessed on 11 April 2022).
18. Satish, S.; Saiganesh, J.; Karthik, T.; Venkateshalu, M. Design and analysis of suspension system for a three wheeler electric vehicle. *J. Adv. Res. Dyn. Control Syst.* **2017**, *9*, 1230–1238.
19. Sindha, J.; Chakraborty, B.; Chakravarty, D. Automatic stability control of three-wheeler vehicles—Recent developments and concerns towards a sustainable technology. *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.* **2017**, *232*, 418–434. [CrossRef]
20. Awal, M.R.; Islam, A.N.; Khan, M.Z.R. Bangladesh power system peak demand shaving through demand side management of the battery operated easy bike load. In Proceedings of the 4th International Conference on Electrical Information and Communication Technology (EICT), Khulna, Bangladesh, 20–22 December 2019; pp. 1–6. [CrossRef]
21. Arefin, M.A.; Mallik, A.; Asfaquzzaman, M. Renewable energy–assisted hybrid three-wheeler: A numerical investigation. *Adv. Mech. Eng.* **2018**, *10*. [CrossRef]
22. Rahman, S.; Saha, S.; Islam, S.N.; Arif, M.T.; Mosadeghy, M.; Haque, M.E.; Oo, A.M.T. Analysis of power grid voltage stability with high penetration of solar PV systems. *IEEE Trans. Ind. Appl.* **2021**, *57*, 2245–2257. [CrossRef]
23. Mulhall, P.; Lukic, S.M.; Wirasingha, S.G.; Young-Joo, L.; Emadi, A. Solar-assisted electric auto rickshaw three-Wheeler. *IEEE Trans. Veh. Technol.* **2010**, *59*, 2298–2307. [CrossRef]
24. Lubna, J.; Aman, A.H.; Morshed, M.M.; Islam, A. Cohesive City and Urban Informality: Battery-bikes in Khulna City. Available online: https://www.academia.edu/14101065/Cohesive_City_and_Urban_Informality_Battery_bikes_in_Khulna_City (accessed on 12 November 2022).

25. Iqbal, M.; Akhter, S.; Ahmad, S. Study on merits and demerits of two transport systems: Battery operated easy bike with CNG operated auto rickshaw at Sylhet City in Bangladesh. *IOSR J. Mech. Civ. Eng.* **2013**, *5*, 25–32. [CrossRef]
26. Sreejith, R.; Rajagopal, K.R. An insight into motor and battery selections for three-wheeler electric vehicle. In Proceedings of the 1s IEEE International Conference on Power Electronics. Intelligent Control and Energy Systems (ICPEICES-2016), Delhi, India, 4–6 July 2016; pp. 1–6. [CrossRef]
27. Arifurrahman, F.; Indrawanto, I.; Budiman, B.A.; Sambegoro, P.L.; Santosa, S.P. Frame modal analysis for an electric three-wheel vehicle. *MATEC Web Conf.* **2018**, *197*, 08001–08006. [CrossRef]
28. Rajper, S.Z.; Albrecht, J. Prospects of electric vehicles in the developing countries: A literature review. *Sustainability* **2020**, *12*, 1906. [CrossRef]
29. Farhana, J.N.; Haslenda, H.; Shin, H.W.; Keng, L.L.; Binti, S.N.S.; Alnie, D.; Andy, T.; Rizki, K.M.; Rika, S.; Ayu, R.S. Electric vehicle adoption in ASEAN. *Prospect and challenges. Chem. Eng. Trans.* **2021**, *89*, 625–630. [CrossRef]
30. Kumar, R.; Jha, A.; Damodaran, A.; Bangwal, D.; Dwivedi, A. Addressing the challenges to electric vehicle adoption via sharing economy: An Indian perspective. *Manag. Environ. Qual. Int. J.* **2020**, *32*, 82–99. [CrossRef]
31. Muzir, N.A.Q.; Mojumder, M.R.H.; Hasanuzzaman, M.; Selvaraj, J. Challenges of electric vehicles and their prospects in Malaysia: A comprehensive review. *Sustainability* **2022**, *14*, 8320. [CrossRef]
32. Mukherjee, S.C.; Ryan, L. Factors influencing early battery electric vehicle adoption in Ireland. *Renew. Sustain. Energy Rev.* **2020**, *118*, 109504. [CrossRef]
33. Egbue, O.; Long, S.; Samaranayake, V.A. Mass deployment of sustainable transportation: Evaluation of factors that influence electric vehicle adoption. *Clean Technol. Environ. Policy* **2017**, *19*, 1927–1939. [CrossRef]
34. Åhman, M. Government policy and the development of electric vehicles in Japan. *Energy Policy* **2006**, *34*, 433–443. [CrossRef]
35. Du, J.; Ouyang, M.; Chen, J. Prospects for Chinese electric vehicle technologies in 2016–2020: Ambition and rationality. *Energy* **2017**, *120*, 584–596. [CrossRef]
36. Du, J.; Ouyang, M. Review of electric vehicle technologies progress and development prospect in China. *World Electr. Veh. J.* **2015**, *6*, 1086–1093. [CrossRef]
37. Helveston, J.P.; Liu, Y.; Feit, E.M.; Fuchs, E.; Klampfl, E.; Michalek, J.J. Will subsidies drive electric vehicle adoption? Measuring consumer preferences in the U.S. and China. *Transp. Res. Part A Policy Pract.* **2015**, *73*, 96–112. [CrossRef]
38. Vaidehi; Dhar, S.; Jayakumar, A.; Lavanya, R.; Dinesh Kumar, M. Techno-economic assessment of various motors for three-wheeler E-auto rickshaw: From Indian context. *Mater. Today Proc.* **2021**, *45*, 6572–6579. [CrossRef]
39. Bagul, T.R.; Kumar, R.; Kumar, R. Real-world emission and impact of three wheeler electric auto-rickshaw in India. *Environ. Sci. Pollut. Res. Int.* **2021**, *28*, 68188–68211. [CrossRef]
40. Priye, S.; Manoj, M.; Ranjan, R. Understanding the socioeconomic characteristics of paratransit drivers and their perceptions toward electric three-wheeled rickshaws in Delhi, India. *IATSS Res.* **2021**, *45*, 357–370. [CrossRef]
41. The New Nation. 1m Easy-Bikes' in Country. Available online: https://thedailynewnation.com/news/149439/1m-easy-bikes-in-country.html (accessed on 30 June 2022).
42. The Daily Star. Easy Bikes Outgrowing Limitations. Available online: https://www.thedailystar.net/business/easy-bikes-outgrowing-limitations-1469200 (accessed on 30 June 2022).
43. Kawamoto, R.; Mochizuki, H.; Moriguchi, Y.; Nakano, T.; Motohashi, M.; Sakai, Y.; Inaba, A. Estimation of CO_2 emissions of internal combustion engine vehicle and battery electric vehicle using LCA. *Sustainability* **2019**, *11*, 2690. [CrossRef]
44. Ekanayake, G.; Patil, M.S.; Seo, J.-H.; Lee, M.-Y. Numerical study of fin geometry on the heat transfer characteristics of 72 V ECU heatsink for an electric three-wheeler. *J. Mech. Sci. Technol.* **2019**, *33*, 1451–1462. [CrossRef]
45. Nahar, N.; Mahiuddin, S.; Hossain, Z. The severity of environmental pollution in the developing countries and its remedial measures. *Earth* **2021**, *2*, 124–139. [CrossRef]
46. Bangladesh Bureau of Statistics. *Consumer Price Index (CPI), Inflation Rate and Wage Rate Index (WRI) in Bangladesh*; Bangladesh Bureau of Statistics: Dhaka, Bangladesh, 2020.
47. Subhana, A.; Zahin, F.; Abid, F.; Khan, M.Z.R. Emergency backup power to a rural hospital in disaster condition. In Proceedings of the 2019 IEEE 4th International Future Energy Electronics Conference (IFEEC), Singapore, 25–28 November 2019. [CrossRef]
48. Limited, B. Category Archives: Electric Auto Rickshaw. Available online: http://beevatech.com/category/electric-auto-rickshaw/ (accessed on 30 June 2022).
49. Mandal, S.; Ahmed, S.; Rabbi, F. Impact of battery driven vehicle on the electricity of Rajshahi city, Bangladesh. In Proceedings of the International Conference on Mechanical, Industrial and Materials Engineering 2015 (ICMIME2015), Rajshahi, Bangladesh, 11–13 December 2015; pp. 1–6.
50. Quang Sheng. 2018 Street Legal New Design Borak or Borac Bangladesh Dhaka Easy Bike. Available online: https://www.pcqs-china.com/2018-street-legal-new-design-borak-or-borac-bangladesh-dhaka-easy-bike.html (accessed on 14 March 2022).
51. Alibaba. China Bajaj Style Auto Rickshaw Price. Available online: https://www.alibaba.com/product-detail/Auto-Rickshaw-China-Bajaj-Style-Auto_1600107839972.html?spm=a2700.7724857.normal_offer.d_image.24367186zjwWVl&s=p (accessed on 14 May 2022).
52. Wahid, M.R.; Budiman, B.A.; Joelianto, E.; Aziz, M. A review on drive train technologies for passenger electric vehicles. *Energies* **2021**, *14*, 6742. [CrossRef]

53. Mohammad, A.; Abedin, M.A.; Khan, M.Z.R. Implementation of a three phase inverter for BLDC motor drive. In Proceedings of the 9th International Conference on Electrical and Computer Engineering, Dhaka, Bangladesh, 20–22 December 2016.
54. Hanselman, D.C. *Brushless Permanent Magnet Motor Design*, 2nd ed.; Magna Physics Publishing: Madison, WI, USA, 2003.
55. Awal, M.R. *Design and Development of an Efficient Charging System for the Battery Operated Vehicles in Bangladesh*; Military Institute of Science and Technology: Dhaka, Bangladesh, 2019.
56. Zhejiang Datai New Energy Co., Ltd. Product-1000W Central Motor. Available online: http://www.tzdatai.com/english/productshow.aspx?id=28 (accessed on 26 March 2022).
57. Jusuf, A.; Nurprasetio, I.P.; Prihutama, A. Macro data analysis of traffic accidents in Indonesia. *J. Eng. Technol. Sci.* **2017**, *49*, 132–143. [CrossRef]
58. Cheah, L.; Heywood, J. Meeting U.S. passenger vehicle fuel economy standards in 2016 and beyond. *Energy Policy* **2011**, *39*, 454–466. [CrossRef]
59. Uttekar, S.S.; Phatak, S.S.; Karandikar, P.B. Social impact on hybrid and retrofitted three-wheelers. *Asian J. Converg. Technol.* **2021**, *7*, 144–149. [CrossRef]
60. Chakravarty, D.; Chakraborty, B.; Sindha, J. System identification and lateral dynamics of the active tilt-controlled electric three wheeler. *J. Dyn. Syst. Meas. Control* **2020**, *142*, 091001. [CrossRef]
61. New Age Bangladesh. Easy Bikes Keep Running on Dhaka Roads. Available online: https://www.newagebd.net/article/119174/easy-bikes-keep-running-on-dhaka-roads (accessed on 30 June 2022).
62. bdnews24 Child Dies from Burns after Kamrangirchar Blast, Toll Rises to 3. Available online: https://bdnews24.com/bangladesh/2021/07/14/child-dies-from-burns-after-kamrangirchar-blast-toll-rises-to-3 (accessed on 14 July 2022).
63. Trovão, J.P.; Dubois, M.R.; Roux, M.-A.; Ménard, É.; Desrochers, A. Battery and SuperCapacitor hybridization for a pure electric three-wheel roadster. In Proceedings of the IEEE Vehicle Power and Propulsion Conference (VPPC), Montreal, QC, Canada, 19–22 October 2015.
64. Podder, S.; Khan, M.Z.R. Comparison of lead acid and Li-ion battery in solar home system of Bangladesh. In Proceedings of the 5th International Conference on Informatics, Electronics and Vision (ICIEV), Dhaka, Bangladesh, 13–14 May 2016; pp. 434–438. [CrossRef]
65. Dufo-López, R.; Cortés-Arcos, T.; Artal-Sevil, J.S.; Bernal-Agustín, J.L. Comparison of lead-acid and Li-Ion batteries lifetime prediction models in stand-alone photovoltaic systems. *Appl. Sci.* **2021**, *11*, 1099–1114. [CrossRef]
66. Weinert, J.X.; Burke, A.F.; Wei, X. Lead-acid and lithium-ion batteries for the Chinese electric bike market and implications on future technology advancement. *J. Power Sources* **2007**, *172*, 938–945. [CrossRef]
67. Arefeen, A.; Shehreen, S.; Islam, A.; Rahman, M.; Rahman, H. Measurement and assessing the effects of harmonics on the grid of Bangladesh power system during EV charging. In Proceedings of the IEEE International Conference on Power, Electrical, and Electronics and Industrial Applications (PEEIACON), Dhaka, Bangladesh, 29 November–1 December 2019; pp. 5–9. [CrossRef]
68. Kudelina, K.; Asad, B.; Vaimann, T.; Rassõlkin, A.; Kallaste, A.; Lukichev, D.V. Main faults and diagnostic possibilities of BLDC motors. In Proceedings of the 27th International Workshop on Electric Drives: MPEI Department of Electric Drives 90th Anniversary (IWED), Moscow, Russia, 27–30 January 2020.
69. Bang, Y.-M.; Patil, M.S.; Seo, J.-H.; Lee, M.-Y. Experimental and numerical study on the thermal performances of battery cell and ECU for an E-Bike. In Proceedings of the AETA 2016: Recent Advances in Electrical Engineering and Related Sciences, Busan, Republic of Korea, 8–10 December 2016; pp. 195–204. [CrossRef]
70. Bangladesh Power Development Board. *Annual Report 2019–2020*; Bangladesh Power Development Board: Dhaka, Bangladesh, 2020; pp. 1–116.
71. Bangladesh Power Development Board. BPDB Daily Generation. Available online: https://www.bpdb.gov.bd/bpdb_new/index.php/site/daily_generation (accessed on 11 April 2022).
72. Saxena, S.; Gopal, A.; Phadke, A. Electrical consumption of two-, three- and four-wheel light-duty electric vehicles in India. *Appl. Energy* **2014**, *115*, 582–590. [CrossRef]
73. Habib, A.K.M.A.; Motakabber, S.M.A.; Ibrahimy, M.I. A comparative study of electrochemical battery for electric vehicles applications. In Proceedings of the 2019 IEEE International Conference on Power, Electrical, and Electronics and Industrial Applications (PEEIACON), Dhaka, Bangladesh, 29 November–1 December 2019; pp. 43–47. [CrossRef]
74. Rahman, M.M.; Khan, M.Z.R. Solar energy based net metered easy-bike charging station in Bangladesh. In Proceedings of the International Conference on Information and Communication Technology for Sustainable Development (ICICT4SD), Dhaka, Bangladesh, 27–28 February 2021; pp. 220–224. [CrossRef]
75. Tasnia, K.; Begum, S.; Tasnim, Z.; Khan, M.Z.R. End-of-life management of photovoltaic modules in Bangladesh. In Proceedings of the 10th International Conference on Electrical and Computer Engineering, Dhaka, Bangladesh, 20–22 December 2018.
76. Wigley, T.M.L. Global-mean temperature and sea level consequences of greenhouse gas concentration stabilization. *Geophys. Res. Lett.* **1995**, *22*, 45–48. [CrossRef]
77. Khan, M.A.; Bokhari, S.F.; Khan, A.; Amjad, M.S.; Butt, A.M.; Rafique, M.Z. Clean and sustainable transportation through electric vehicles—A user survey of three-wheeler vehicles in Pakistan. *Environ. Sci. Pollut. Res. Int.* **2022**, *29*, 45560–45577. [CrossRef]
78. Kumar, R.R.; Chakraborty, A.; Mandal, P. Promoting electric vehicle adoption: Who should invest in charging infrastructure? *Transp. Res. Part E Logist. Transp. Rev.* **2021**, *149*, 102295. [CrossRef]

79. Pramod, K.N.; Prashant, D.H.; Akash Shetty, K.K.; Abhishek, B. A review on three wheeler electric vehicle. *Int. J. Sci. Res. Eng. Trends* **2021**, *7*, 2432–2434.
80. Kosai, S.; Zakaria, S.; Che, H.S.; Hasanuzzaman, M.; Tan, C.; Ahmad, R.D.R.; Abbas, A.R.; Nakano, K.; Woon, W.K.; Amer, A.H.A. Estimation of greenhouse gas emissions of petrol, biodiesel and battery electric vehicles in Malaysia based on life cycle approach. *Sustainability* **2022**, *14*, 5783. [CrossRef]
81. Khaligh, A.; Zhihao, L. Battery, ultracapacitor, fuel cell, and hybrid energy storage systems for electric, hybrid electric, fuel cell, and plug-in hybrid electric vehicles: State of the art. *IEEE Trans. Veh. Technol.* **2010**, *59*, 2806–2814. [CrossRef]
82. Laurischkat, K.; Jandt, D. Techno-economic analysis of sustainable mobility and energy solutions consisting of electric vehicles, photovoltaic systems and battery storages. *J. Clean. Prod.* **2018**, *179*, 642–661. [CrossRef]
83. Eco-Business. Legalising Bangladesh 'Easy Bike' Taxis Could Drive Safer, Greener Industry. Available online: https://www.eco-business.com/news/legalising-bangladesh-easy-bike-taxis-could-drive-safer-greener-industry/ (accessed on 13 November 2022).
84. Victor Chombo, P.; Laoonual, Y.; Wongwises, S. Lessons from the electric vehicle crashworthiness leading to battery fire. *Energies* **2021**, *14*, 4802. [CrossRef]
85. Christensen, P.A.; Anderson, P.A.; Harper, G.D.J.; Lambert, S.M.; Mrozik, W.; Rajaeifar, M.A.; Wise, M.S.; Heidrich, O. Risk management over the life cycle of lithium-ion batteries in electric vehicles. *Renew. Sustain. Energy Rev.* **2021**, *148*, 111240. [CrossRef]
86. Mulhall, P.; Emadi, A. Comprehensive simulations and comparative analysis of the electric propulsion motor for a solar/battery electric auto rickshaw three-wheeler. In Proceedings of the 35th Annual Conference of the IEEE Industrial Electronics Society, Porto, Portugal, 3–5 November 2009; pp. 3785–3790. [CrossRef]
87. Wahid, M.R.; Joelianto, E.; Azis, N.A. System identification of switched reluctance motor (SRM) using black box method for electric vehicle speed control system. In Proceedings of the 6th International Conference on Electric Vehicular Technology (ICEVT), Bali, Indonesia, 18–21 November 2019; pp. 208–212.
88. Cao, Z.; Mahmoudi, A.; Kahourzade, S.; Soong, W.L. An overview of electric motors for electric vehicles. In Proceedings of the 2021 31st Australasian Universities Power Engineering Conference (AUPEC), Perth, Australia, 26–30 September 2021; pp. 1–6.
89. Xu, W.; Zhu, J.; Guo, Y.; Wang, S.; Wang, Y.; Shi, Z. Survey on electrical machines in electrical vehicles. In Proceedings of the IEEE International Conference on Applied Superconductivity and Electromagnetic Devices, Chengdu, China, 25–27 September 2009.
90. Mohammadi, A.S.; Trovão, J.P.F. System-level optimization of hybrid excitation synchronous machines for a three-wheel electric vehicle. *IEEE Trans. Transp. Electrif.* **2020**, *6*, 690–702. [CrossRef]
91. Mondal, M.A.H.; Denich, M. Assessment of renewable energy resources potential for electricity generation in Bangladesh. *Renew. Sustain. Energy Rev.* **2010**, *14*, 2401–2413. [CrossRef]
92. Power Division, Ministry of Power, Energy and Mineral Resources, Government of the People's Republic of Bangladesh. *Energy Efficiency and Conservation Master Plan up to 2030*; Government of the People's Republic of Bangladesh: Dhaka, Bangladesh, 2015.
93. Ministry of Power, Energy and Mineral Resources, Government of the People's Republic of Bangladesh. *Power System Master Plan 2016 Summary*; Government of the People's Republic of Bangladesh: Dhaka, Bangladesh, 2016.
94. Uprety, S.; Sapkota, R.C. Energy scenario of three wheeler electric and gasoline vehicle in Hetauda. *J. Adv. Coll. Eng. Manag.* **2021**, *6*, 123–129. [CrossRef]
95. The Financial Express. Move to Legalise Electric Vehicles. Available online: https://thefinancialexpress.com.bd/trade/move-to-legalise-electric-vehicles-1548302855 (accessed on 8 September 2022).
96. Dhaka Tribune. PDB for Bringing Battery-Run Vehicles under Tariff Regulations. Available online: https://www.dhakatribune.com/bangladesh/power-energy/2017/09/27/pdb-bringing-battery-run-vehicles-tariff-regulations (accessed on 30 June 2022).
97. The Financial Express. BEPRC Moves to Formulate Guideline for Easy Bikes. Available online: https://thefinancialexpress.com.bd/national/beprc-moves-to-formulate-guideline-for-easy-bikes-1615472819 (accessed on 11 April 2022).
98. SREDA. *Electric Vehicle Charging Guideline*; Ministry of Energy and Mineral Resource, Government of the People's Republic of Bangladesh: Dhaka, Bangladesh, 2022; pp. 1–22.
99. IEC 61851-1: 2017-02; Electric Vehicle Conductive Charging System—Part, 1. Available online: https://webstore.iec.ch/publication/33644 (accessed on 16 December 2022).
100. IEC 61851-23: 2014; Electric Vehicle Conductive Charging System—Part 23: DC Electric Vehicle Charging Station. Available online: https://webstore.iec.ch/publication/24906 (accessed on 16 December 2022).
101. IEC 61851-23: 2014; Electric Vehicle Conductive Charging System—Part 24: Digital Communication between a d.c. EV Charging Station and an Electric Vehicle for Control of d.c. Charging. Available online: https://webstore.iec.ch/publication/6033 (accessed on 16 December 2022).
102. ISO 17409:2020; Electrically Propelled Road Vehicles—Conductive Power Transfer—Safety Requirements. Available online: https://www.iso.org/standard/72880.html (accessed on 16 December 2022).
103. IEC 60947-2:2016; Low-Voltage Switchgear and Controlgear—Part 2: Circuit-Breakers. Available online: https://webstore.iec.ch/publication/65448 (accessed on 16 December 2022).
104. IEC 60947-6-2:2020; Low-Voltage Switchgear and Controlgear—Part 6-2: Multiple Function Equipment—Control and Protective Switching Devices (or Equipment) (CPS). Available online: https://webstore.iec.ch/publication/61649 (accessed on 16 December 2022).

105. IEC 60364; International Standard on Electrical Installations of Buildings. Available online: https://webstore.iec.ch/searchform&q=60364 (accessed on 16 December 2022).
106. IEC 62305:2022; SER Series. Protection against Lightning—ALL PARTS. Available online: https://webstore.iec.ch/publication/6797 (accessed on 16 December 2022).
107. IEC 62893-1:2017; Charging Cables for Electric Vehicles for Rated Voltages up to and Including 0.6/1 kV—Part 1: General Requirements. Available online: https://webstore.iec.ch/publication/30590 (accessed on 16 December 2022).
108. IEC 60529:1989/AMD2:2013/COR1:2019; Corrigendum 1—Amendment 2—Degrees of Protection Provided by Enclosures (IP Code). Available online: https://webstore.iec.ch/publication/64427 (accessed on 16 December 2022).
109. Newage Bangladesh. BRTA Initiates Move to Finalise Electric Vehicle Guidelines. Available online: https://www.newagebd.net/article/127407/brta-initiates-move-to-finalise-electric-vehicle-guideline (accessed on 11 November 2022).
110. The Daily Star. Govt Readies Rules to Pave Way for Electric Vehicles. Available online: https://www.thedailystar.net/business/economy/news/govt-readies-rules-pave-way-electric-vehicles-2912346 (accessed on 10 November 2022).
111. Dhaka Tribune. E-Vehicle Guideline Delay Frustrates Local Manufacturers. Available online: https://www.dhakatribune.com/bangladesh/2022/07/13/e-vehicle-guideline-delay-frustrates-local-manufacturers (accessed on 10 November 2022).
112. Ministry of Industries, Government of the People's Republic of Bangladesh. *Automobile Industry Development Policy, 2020 (Draft)*; Government of the People's Republic of Bangladesh: Dhaka, Bangladesh, 2020.
113. Bokare, P.S.; Maurya, A.K. Study of acceleration behaviour of motorized three wheeler in India. *Transp. Res. Procedia* **2016**, *17*, 244–252. [CrossRef]