Commercialization of Electric Vehicles in Hong Kong

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Abstract: Road vehicles are responsible for air pollution in Hong Kong, and electric vehicles (EVs) are a promising alternative to internal combustion engine vehicles as the city is transitioning to clean energy. In this work, EV adoption in Hong Kong is investigated and analyzed, including the global EV markets, present EV status in Hong Kong, local challenges facing EV development, suggestions for EV promotion in Hong Kong, emerging technologies, and decommissioning of batteries and EVs. The challenges of EVs include insufficient charging infrastructures, inadequate management of public charging facilities, difficulties in EV repair and maintenance, “dead mileage” during charging, unacceptable long charging times, and limited commercial EV models. Strategies such as providing incentives and bonuses for commercial EVs, offering high-power quick-charging facilities, actively developing commercial EVs, installing more charging infrastructures for private EVs, building connections among stakeholders, encouraging the participation of the private sector to promote fee-based services, and supporting the development of innovative technologies should be implemented to promote EVs in Hong Kong. Emerging technologies for EVs such as wireless charging, smart power distribution, vehicle-to-grid and vehicle-to-home systems, connected vehicles, and self-driving are discussed. Eco-friendly decommissioning of EV batteries can be realized by recycling and second-life applications. This paper serves as a reference and guide for the sustainable and smart evolution of the transportation sector in Hong Kong and other global large cities.

Keywords: electric vehicles; adoption; Hong Kong City; challenges; emerging technologies; decommissioning of batteries

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1. Introduction

Green technology is in high demand in this century [1,2]. In particular, the rapid growth of modern cities has led to increased transportation needs, giving rise to heavy traffic, consumption of a large amount of fossil fuels, and ensuing environmental problems [3]. According to the Environmental Protection Department (EPD) of the Hong Kong Special Administrative Region (Hong Kong SAR), the road transport sector is Hong Kong's second-largest cause of air pollution, generating 49,190 tons of air pollutants, which is only slightly lower than that of navigation emissions. Table 1 presents the 2018 air pollutant emission inventory compiled by the Hong Kong EPD. The road transport emissions accounted for approximately 18.3% of total nitrogen oxides (NO_x), 9.7% of total respirable suspended particles (RSPs), 11.5% of total fine suspended particles (FSPs), 21.5% of total volatile organic compounds (VOCs), and 49.6% of total carbon monoxide (CO). The EPD has also reported that the number of days when the roadside air pollution index reaches the “very high” level (that is, air pollution index > 100) continues to increase. Air pollution

caused by traffic is posing increasing threats to the health of Hong Kong citizens, and has attracted public attention [4,5]. A densely populated modern city such as Hong Kong needs a more environmentally friendly transportation system to reduce or even eliminate air pollution in sustainable urban development [6,7]. Therefore, vehicle emissions must be controlled and reduced by implementing cleaner technologies.

Table 1. 2018 Hong Kong air pollutant emission inventory (source: Environmental Protection Department of Hong Kong SAR).

Pollutant Source Categories	SO ₂	NO _x	RSP	FSP	VOC	CO
Public electricity generation	7630	23,550	630	320	410	3470
Road transport	40	15,300	390	360	4800	28,300
Navigation	8000	30,680	1380	1280	2370	15,640
Civil aviation	560	6270	60	60	570	4280
Other combustion	190	7780	640	600	730	5410
Noncombustion	N/A	N/A	930	500	13,460	N/A
Total without biomass burning	16,420	83,580	4020	3120	22,330	57,100
Biomass burning	50	250	3100	2540	670	7240
Total with biomass burning	16,460	83,840	7120	5650	23,000	64,330

Note: unit = tons.

Boasting zero air pollution on the road, EVs are the most promising alternative means of transportation [7–9]. By reducing carbon emissions and other pollutants, EVs have a positive impact on the environment. Hybrid vehicles (HVs) have been developed to reduce the use of internal combustion engines (ICEs) by combining them with electric motors [3,4]. However, HVs are considered transition models, since they still consume fossil fuels and exhaust pollutants. With the advent of pure battery electric vehicles (PBEVs), the emission of greenhouse gases can be addressed. PBEVs are zero-emission vehicles that operate entirely on electricity produced by batteries. Over the years, the Hong Kong government has committed to promoting EVs for individuals and commercial organizations [10]. In March 2009, the government established a supervision committee chaired by the secretary of finance to popularize EVs in Hong Kong. The government established a Pilot Green Transport Fund in 2010, costing HKD 300 million to support green evolution and technological innovations in the road transport sector [11]. Hence, it is necessary to conduct a comprehensive study to investigate the global pattern of EVs and specific application in the Hong Kong SAR for sustainable energy development.

The development of new technologies for EVs can broaden the market, and the market demand also promotes the emergence of new technologies [12,13]. The mass marketization of EVs still faces several technical challenges, including driver range anxiety, insufficient charging facilities, and grid stress [7,8,14]. The development of some emerging technologies such as wireless charging, smart power distribution, vehicle-to-grid and vehicle-to-home systems, connected vehicles, and self-driving plays an important role in solving the existing technical bottlenecks of EVs and promoting the attractiveness of EVs to consumers. As the number of EVs increases dramatically in Hong Kong, the retirement of batteries and EVs will also increase over time. The recycling and reuse of vehicle batteries and accessories are necessary to protect the environment. Recycling lithium-ion batteries entails certain costs and potential waste. Giving a second life to these batteries can ensure that they are used efficiently and delay their disassembly and recycling processes. Therefore, decommissioned vehicle batteries should first consider secondary applications, and then undergo a cleaner recycling process after the battery life is completely exhausted. Although significant progress has been made in some basic research on EV technologies and materials, there is still a lack of focus on the commercialization of EVs, especially in large cities such as Hong Kong, where the urban environment and transportation conditions are very complex.

Hence, a timely review summarizing the recent progress and commercialization prospect is highly needed.

The major goal of this EV study is to examine the global trend of EV usage and how it may be applied in Hong Kong to help with smart city development. This work firstly focused on the commercialization progress of EVs in Hong Kong. In comparison to earlier EV reviews, our work provides the most up-to-date industrial development, as well as follow-up recommendations for EV promotion and smart mobility adoption, in Hong Kong. Despite this, the current study conducted research on a number of technologies that have emerged in recent years, including wireless charging, smart power distribution, vehicle-to-grid and vehicle-to-home systems, connected vehicles, and self-driving. This review begins with the current global market of EVs and the status of EVs in Hong Kong. After describing the local challenges facing EV adoption and development, the corresponding strategies and recommendations to promote EVs in Hong Kong are provided. Emerging technologies are demonstrated, with an emphasis on how those technologies would help EV adoption in Hong Kong. Finally, the challenges and opportunities of decommissioning batteries and EVs are discussed. This paper offers perspectives and recommendations on both green transportation and the burgeoning smart mobility sector in Hong Kong and other major cities worldwide.

2. Methodology

Market surveys and desktop research on EV commercialization among the world's major economies are adopted in this study, and governmental policies in international markets with regard to EV commercialization are examined as a guideline to help identify specific needs relevant to the Hong Kong context that will help us to achieve green transportation by adopting EVs in both the private and commercial sectors. The four main areas in the EV infrastructure and ecosystem are investigated: (a) government measures that promote the use of EVs, (b) charging infrastructures for EVs, (c) emerging technologies of EVs, and (d) decommissioning of EVs and batteries. The statistical data in this work are derived from the Environmental Protection Department and Transport Department of Hong Kong SAR. The literature review adopts 111 publications in the databases of Google Scholar and Web of Science.

3. Global EV Markets

EVs are generally regarded as the “greener” and “cleaner” vehicles, and major automakers in the world will be transitioning to EVs in the next 10 to 15 years [15]. Several countries have declared a ban on the selling of internal combustion engine vehicles (ICEVs) in the next 5 to 20 years. Norway, for example, expects to phase out ICEVs by 2025, with France and the United Kingdom following suit by 2040.

3.1. “Top Seven” EV Markets

In descending order of market penetration, the top five EV countries are the Kingdom of Norway, the Netherlands, the Kingdom of Sweden, the French Republic, and the United Kingdom. Since the ownership of EVs in mainland China and the United States accounts for about 45% and 22% of the global market share (International Energy Agency, 2019), respectively, the status of the EV market in mainland China and the United States is also discussed in this section.

Norway led the pack in terms of the EV adoption rate in 2019 as a result of incentives from the government [16,17]. The collaborative efforts of charging facility producers, power companies, and charging station owners has led to the emergence of the electric mobility value chain [18]. The Netherlands is one of the countries with the highest penetration rate of EVs in the world, which is mainly driven by incentives including carbon-dioxide-based tax rebates for vehicles emitting less than 50 g of carbon dioxide per kilometer, consequently spurring substantial growth of the EV market [19]. Sweden's infrastructure is already adequate, and people can easily use EV chargers [20]. The French government

vigorously promoted EVs to achieve the goal of 2 million EVs on the road by 2020 [21]. French automakers such as Renault, Peugeot S.A., and Bolloré SE released their first EVs in 2012, and BMW chose France as the test site for its new electric model Mini. In addition, the Renault–Nissan–Mitsubishi Alliance partnership is working on a fully electric powertrain system with a rated power between 15 kW and 100 kW. The United Kingdom strongly supports EVs through incentives and subsidies [16], and consequently, the United Kingdom's EV market share is rapidly expanding, especially in private cars and charging infrastructures [22]. Mainland China has the biggest EV industry in the world [23], and in 2019, approximately 821,000 pure EVs and 203,000 plug-in hybrid vehicles were sold. Sales of new energy vehicles increased by 3% compared to those in 2018, and mainland China accounted for almost half of the global EV stock in 2019 [24]. At the same time, the United States is one of the top players. In 2019, the United States accounted for about a quarter of the global total number of EVs, behind only China, and the “green” priority of President Joe Biden is going to further accelerate the development and acceptance of EVs in the United States.

3.2. Phasing out ICE Vehicles in Various Countries

Some countries are planning to prohibit the selling of ICEVs in the near future in order to reduce emissions from vehicle exhaust. Norway, as the country with the largest EV penetration, has set a clear goal: by 2025, all new passenger vehicles sold must have zero emissions [25]. The French government has recently announced that it will stop selling gasoline and diesel vehicles by 2040 in order to abide by the Paris Climate Agreement [26]. The United Kingdom will also ban the sale of new gasoline and diesel vehicles by 2040 as part of the highly anticipated Clean Air Plan [27]. The Netherlands plans to ban the use of diesel and gasoline vehicles by 2025, while Germany plans to phase them out starting in 2030 [28]. India is also planning to phase out gasoline and diesel vehicles [28], and by 2040, most of the vehicles in India will likely be electric.

3.3. Actions of Automakers

In response to the policies implemented by various countries, major automakers are stepping up EV production and sales. Starting in 2020, all new models released by Volvo will be fully or partially driven by batteries [29], pointing to the “historical end” of ICEVs. From 2019 to 2021, Volvo introduced five 100% pure EV models, and following in the footsteps of Volvo, Jaguar Land Rover has also announced new models with pure ICEs, and from 2020, all their new models will be fully electric or hybrid. In terms of electrification of the automotive product line, Daimler is one of the most ambitious, planning to market 10 new EV models and upgrading ~20% of other models to be powered by batteries by 2022 [30]. Volkswagen has announced that by 2030, the company will invest more than USD 24 billion to produce EVs similar to Mercedes-Benz. Volkswagen has set a goal of launching 80 new EVs by 2025, and plans to upgrade its 300 existing models to become electric by 2030 [31].

4. Present Status of EVs in Hong Kong

According to the Transport Department of the Hong Kong government, the stock of registered EVs in Hong Kong was 13,358 at the end of November 2019 (Table 2), representing a 16-fold increase in just 5 years compared with 782 in 2014. Currently, the Transport Department of Hong Kong SAR has approved 105 EV models, including 76 private car models and 29 commercial vehicle models from 10 economies to drive on the road, as shown in Table 3.

Table 2. Registered EVs by types in Hong Kong (source: Transport Department of Hong Kong SAR).

Vehicle Type	Number of Vehicles by November 2019	Change in Percentage Compared with Data by August 2014
Motorcycles	18	−60.0%
Private cars	13,067	+2437.1%
Taxis	0	−100.0% (from 48 to 0)
Franchised buses	34	N/A (from 0 to 34)
Private buses	2	−50.0%
Private light buses	6	+50.0%
Other nonfranchised public buses	8	+300.0%
Light trucks	120	+140.0%
Medium trucks	0	−100.0% (from 2 to 0)
Special-purpose vehicles	104	−7.1%
Total registered EVs	13,358	+1608.2%

Table 3. Typically approved EV models in Hong Kong (source: Transport Department of Hong Kong SAR).

Category	Model	Battery Capacity	Mileage	Charging
Private car	Euauto MyCar	9.6 kWh	~97 miles	Charging power: 2100 W; recharge time: 8–10 h (quick charge: 3 h); charger: 48 V DC
Private car	Mitsubishi iMiEV	16.0 kWh	~160 km	15 A 240 V AC (3.6 kW) on the SAE J1772-2009 inlet, optional CHAdeMO DC rapid charging, adapters for domestic AC sockets (110–240 V)
Private car	Nissan LEAF	40.0–60.0 kWh	243–364 km	3.6 kW (3.3 kW output) and optional 6.6 kW (6.0 kW output) 240 V AC on SAE J1772-2009 inlet, max 44 kW 480 V DC on CHAdeMO inlet, adapters for domestic AC sockets (110–240 V)
Private car	Tesla Model 3	54.0–82.0 kWh	354–504 km	11 kW onboard charger for Type 2 AC charging as standard, in addition to rapid DC capability
Private car	Tesla Model S	75.0–100.0 kWh	400–650 km	16.5 kW onboard Type 2 charger as standard which covers all applications apart from rapid DC charging
Private car	Tesla Roadster	53.0 kWh	~393 km	Proprietary inlet, 16.8 kW (70 A 240 V) with HPWC outlet and with the SAE J1772-2009 adapter, adapters for domestic AC sockets
Private car	Tesla Model X	60.0–100.0 kWh	383–523 km	Slow/fast: Type 2, max AC 1-phase rate: 7.4 kW, max AC 3-phase rate: 16.5 kW; rapid: supercharger, max DC rate: 100–200 kW
Private car	BMW i3	18.2–37.9 kWh	130–322 km	7.4 kW onboard charger on IEC Combo AC, optional 50 kW Combo DC, DCFC standard on 2015+ models in the US market.
Private car	Renault Fluence Z.E.	22.0–36.0 kWh	145–233 km	7 kW onboard charger (max. 240 V/30 A), optional upgrade to Zoe's Chameleon charger (43 kW–380 VAC 3 phase)
Private car	Renault ZOE	22.0–52.0 kWh	210–395 km	Max 50 kW on CCS and max 22 kW on Type 2
Private car	BYD e6	61.0–80.0 kWh	300–400 km	Onboard charger: 3 × 32 A, max. 3.7 kW; AC charge port: Type 2; charging point: charging time (0–>400 km); DC quick-charge port: CHAdeMO
Private car	Smart Forfour	17.6 kWh	~130 km	3-pin plug charge 8.5 h, charge time 3 h 18 min, connector type Type 2, no rapid charge
Private car	Volkswagen e-GOLF	24.2 kWh	129–190 km	7.2 kW onboard charger for AC charging, in addition to the rapid 50 kW DC option

Table 3. Cont.

Category	Model	Battery Capacity	Mileage	Charging
Private car	Hyundai Ioniq Electric	28.0–38.3 kWh	200–274 km	7.2 kW onboard charger for Type 2 AC charging, in addition to rapid 50 kW DC capability
Private car	Hyundai Kona Electric	39.2–64.0 kWh	303–484 km	7.2 kW onboard charger for Type 2 AC charging, in addition to rapid 50 kW DC capability
Private car	Jaguar I-PACE EV400	90.0 kWh	396–470 km	11 kW AC (7 kW AC), 100 kW DC
Private car	KIA Niro EV+	39.2–64.0 kWh	288–455 km	7.2 kW onboard charger as standard for Type 2 AC charging, in addition to rapid 77 kW DC capability
Commercial vehicle	Renault Kangoo Van Z.E.	22.0–33.0 kWh	~170 km	Type 2 with up to 4.6 kW of charging power
Commercial vehicle	Mitsubishi Minicab-MiEV	10.5–16.0 kWh	100–150 km	Standard with a 200 V AC (15 A) cable that fits outdoor sockets used for EV battery charging, a 100 V AC (10 A) cable, and a quick-charging connector are available as factory-supplied options.
Commercial vehicle	Nissan E-NV200 Full Panel Van	40 kWh	200–300 km	Two charging standards for its inlets—Type 1 and CHAdeMO, fast charging (6.6 kW on-board), Mode3 32 A T2 cable
Commercial vehicle	DFSK EC35	41.4 kWh	~233 km	AC and DC charging is supported, with a full AC charge taking 7–8 h
Commercial vehicle	JOYLONG EW4	57.6 kWh	~220 km	AC slow charging and DC fast charging within 1.5 h
Commercial vehicle	Wuzhoulong FDG6700EVG	101 kWh	~180 km	EVQC 31 quick-charging system, output: 400 VDC/120 A, charging standard: GB/T 20234
Commercial vehicle	FDG6102EVG	324 kWh	~280 km	125 kW, ~4–5 h

4.1. Current State of Private Electric Cars

Figure 1 indicates the amount of private EVs in Hong Kong City from 2014 to 2019. In November 2019, the figure had increased by 25 times, reaching 13,067, although it was only 2.08% of the total sector. From August 2014 to September 2015, the number of EVs increased steadily, with an average monthly increase of about 153 units. The main consumer concerns about EVs are the absolute mileage per charge, availability of charging infrastructure, and acceleration and dynamic performance. At that time, the range of an EV was only about 100–120 km per full charge, thus explaining the local reluctance to buy EVs. However, when Tesla EVs demonstrated a range of more than 300 km per charge in 2015, the situation changed. In 2015, Tesla sold an EV model with a range of more than 200 km per charge in Hong Kong, and the company has been dominant locally.

4.2. Current Status of Commercial EVs

The market penetration of commercial EVs is significantly less than that of private electric cars, as shown in Figure 2. There were only 269 registered commercial EVs on average, and the scale of adoption was only 0.13%. Table 2 indicates that the commercial vehicle market is dominated by light trucks and special purpose vehicles (total of 224 vehicles) and 34 franchised buses. In Hong Kong, there are currently no electric taxis, and BYD's pilot project of electric taxis in mainland China also ceased in 2015.

Figure 1. The stock of registered private EVs (source: Transport Department of Hong Kong SAR).

Figure 2. The stock of registered commercial EVs (source: Transport Department of Hong Kong SAR).

4.3. Current Status of Charging Facilities

At present, a variety of EV chargers and corresponding charging standards exist in Hong Kong. Based on the power, the chargers can be divided into standard type (AC power ≤ 3.7 kW), medium type (AC power between 3.7 kW and 22 kW), and quick type (AC power between 22 kW and 44.5 kW or DC power ≤ 400 kW) [32,33], as shown in Table 4. In December 2019, a total of 2929 public EV chargers were scattered in 18 districts in Hong Kong, including 1108 medium chargers, and there were 588 quick chargers within about 10 km. In order to provide efficient public charging facilities, the Hong Kong government has installed public charging facilities in parking lots. In 2015, 110 standard chargers were upgraded to medium-sized ones, and in 2017, another 170 standard chargers were upgraded to medium-sized. Public quick chargers compatible with multiple standards such as the European and American Combined Charging System (CCS), Japanese CHAdeMO, and European IEC Type 2 AC three-phase are also being gradually installed.

Table 4. Typical EV chargers and corresponding charging standards in Hong Kong.

Country of Production	Standard Charger (AC Power ≤ 3.7 kW)	Medium Charger (AC Power between 3.7 kW and 22 kW)	Quick Charger	
			(AC Power between 22 kW and 44.5 kW)	(DC Power ≤ 400 kW)
China	Type I	GB/T 20234 Part2: AC charging coupler		GB/T 20234 Part 3: DC charging coupler
South Korea	Type A/C	IEC 62196-2 Type 2		CCS Combo 1 (IEC 62196-3)
Japan	Type B	SAE J1772 Type 1	N/A	CHAdEMO

The number of Hong Kong's public EV charging facilities from 2013 to 2019, can be seen in Figure 3. The public EV charging facilities were installed in government parking lots, public housing estates, shopping malls, and other places. The amount of medium and quick chargers is increasing, while the amount of unpractical standard chargers is decreasing. However, an international quick-charging standard has not yet been developed. Current standards include the CCS, CHAdEMO, IEC Type 2 AC 3 phase, and China National Standard (GB). However, these standards are not compatible. Recently, it has been reported that EV charger manufacturers have introduced multiple standard products to enhance compatibility [34,35]. The existing multiple standard quick chargers in Hong Kong can be compatible with CCS, CHAdEMO, and IEC Type 2 AC 3 phase. However, the quick chargers of GB are still dedicated.

Figure 3. The number of public EV chargers in Hong Kong (source: Transport Department of Hong Kong SAR).

5. Challenges Facing EV Development in Hong Kong

5.1. Challenges of Private Electric Cars

- Insufficient charging infrastructures

The survey shows that most private car owners are willing to buy EVs if they have charging facilities at home. However, most charging facilities are in public areas such as public parking lots and shopping malls, thus making overnight charging impractical.

- Inadequate management of public charging facilities

One problem that plagues EV owners is that public parking spaces with charging piles are often occupied by nonelectric cars [36]. Owing to the shortage of charging facilities, poor parking management only exacerbates the problem. Moreover, EVs occupy these public charging sites after charging stations even after charging is completed, and public awareness of this must be improved.

- Inconvenient EV repair and maintenance

The drive system and powertrain of EVs differ from those of traditional ICE vehicles, and new repair and maintenance techniques are required. EVs are equipped with a high-voltage powertrain that may cause potential electric dangers and fire hazards [37,38], so ICE mechanics require special training. At present, most EV manufacturers keep their technical details confidential, and many EV models must be returned to the original factories for repair, thereby prolonging the service time and raising the cost.

5.2. Challenges of Commercial EVs

- Insufficient parking spaces and charging infrastructures

There were 73,053 commercial vehicles in Hong Kong in 2018, but only 46,958 parking spaces, according to a survey by the Audit Commission. Most commercial vehicles are parked temporarily in the countryside. Since the power supply in many temporary parking lots is limited, there is little incentive to install charging facilities.

- “Dead mileage” during charging

Commercial EVs need to use public charging facilities just like private electric cars. However, part of the electrical capacity is consumed when they return to the warehouse after charging, and the “dead mileage” lowers the valid mileage and uptime.

- Long charging times

Compared with private EVs, commercial EVs are usually heavier and require a larger battery capacity and longer charging time [39,40]. Although about 1500 places in Hong Kong have installed EV supply equipment (EVSE), about 1200 of them are only equipped

with standard and medium chargers, requiring more than 3 h to charge a heavy vehicle thoroughly. However, a charging time of less than 1 h is needed for commercial EVs.

- Limited commercial EV models

EV manufacturers have mainly focused on passenger vehicles such as cars, minibuses, and buses, while commercial vehicles are limited. The development of electric trucks, cranes, oil tankers, garbage collection vehicles, pressure tankers, and construction vehicles is slower, and diesel engines are still prevalent.

5.3. Challenges of Charging Facilities

- Lack of universal standard for medium chargers and lack of a multistandard for quick chargers

The medium chargers of the IEC Type 2 standard are suitable for EVs produced in Europe, and these chargers can also be applicable to EVs produced in the US and Japan through a conversion cable (compatible communication protocol between the SAE J1772 standard and the IEC Type 2 standard). However, the international unified quick-charging standard has not yet been formulated.

- Insufficient upgrading of EV chargers

In order to meet the needs of the new generation of EVs, it is necessary to continuously upgrade the existing slow-charging level 1 standard chargers to medium and quick chargers.

- Lack of a centralized database of EV chargers

There is an urgent need to establish and maintain a central database of EV chargers to provide EV drivers with real-time status and location information on distributed chargers. With the help of the Internet of Things, EV charging service providers can broadcast the location, availability, and charging standards of shared chargers via mobile and PC applications. Currently, there is still no central database for information sharing among different charging service providers, which requires government coordination and participation.

- Lack of load management technologies

The availability of sufficient chargers is critical to the adoption and promotion of EVs. Load management technology can analyze and regulate the power distribution of each EV charger in real time, allowing EVs to efficiently share the charging station's available electric power supply. Load management technology provides a smart, cost-effective, and practical solution to install as many as possible EV chargers in areas with limited electricity supply. Several charging service providers, charger manufacturers, and research institutions in Hong Kong have developed prototype load-control systems. Although the technologies are currently being trialed on a pilot or small scale, they are expected to become increasingly significant as the demand for EV chargers grows.

5.4. Strategies to Promote EVs in Hong Kong

- Providing incentives and bonuses for commercial EVs

In Hong Kong, commercial vehicles that run on diesel emit a large number of particulate matters (PMs) and nitrogen oxides (NO_x) to the environment [41,42]. Pollutants increase the ambient temperature and have a significant impact on the health of residents. Similar to the current measures implemented in London and Beijing, the Hong Kong government should strive to convert commercial vehicles to EVs; for example, buses. Replacing diesel buses with electric ones can significantly reduce PMs and NO_x in the air. There are only three bus companies in the city and it would be relatively easy to promote the use of electric buses by introducing incentives. Similarly, taxis and other commercial vehicles can also be subjected to phased conversion to EVs. In fact, EV technology can be combined with emerging self-driving, artificial intelligence, 5G, big data, battery swapping, wireless charging, supercapacitors, and other new technologies to better attract consumers.

- Offering high-power quick-charging facilities

The daily operating time of commercial vehicles exceeds 12 h, and timetables must be strictly followed. The operation of taxis is similar, and the time left for charging is limited and should not be more than 1 h. Therefore, it is necessary to provide commercial vehicles with high-power quick-charging facilities of more than 200 kW so that charging can be accomplished within 30 min.

- Actively developing commercial EVs

In December 2019, there were 13,866 EVs registered in Hong Kong, compared to about 100 in 2010. At present, the Transport Department has approved 108 EV models, including 78 private car models and 30 public bus and freight vehicle models. In November 2019, the total number of registered medium-size, heavy-duty, and special-purpose vehicles such as cranes, tank trucks, dump trucks, tractors, garbage trucks, etc., exceeded 45,000. Local R&D institutions should cooperate with automakers in mainland China and overseas to develop customized electric medium and heavy-duty vehicles to meet the local traffic conditions and needs.

- Installing more charging infrastructures for private EVs

The government should further promote and deploy EVSE by providing incentives, tax breaks, and pilot programs. Although private EVs are increasing steadily, the lack of charging infrastructures has impeded the growth. Although high-power quick chargers can complete full charging within 30 min, the cost is high, and therefore, the best combination of charging facilities should cover both quick and medium chargers, while slow-speed standard chargers should be eliminated in due course.

- Building connections among stakeholders

Stakeholders in the EV charging industry in Hong Kong include the government, power companies, charging service providers, property management offices, universities, R&D institutions, and all EV users. They should jointly formulate strategies and roadmaps to encourage further adoption of EVs in Hong Kong and expand the EV charging network. Stakeholder cooperation can promote the sharing of front-line opinions and data. For example, policymakers and industry leaders can use big data analysis and open data strategies to plan the distribution and density of EV charging facilities in Hong Kong.

- Encouraging the participation of the private sector to promote fee-based services

The Hong Kong government, like most overseas governments, lists household charging as the most suitable daily charging method for general EV users. The second recommendation is charging in workplaces and semipublic places. The third recommendation is the public EV charging service. However, it is difficult for policymakers alone to successfully implement this priority strategy. The private sector should also contribute to the development of private and public EV charging facilities. The business model of paid services can attract more companies to enter this market. The “user-pays” principle is conducive to the recovery of operating and maintenance costs, and encourages EV users to practice environmentally friendly travel. This mode of operation can share the burden of EV charging services and respond to the growing demand for EV charging sustainably.

- Supporting the development of innovative technologies

EVs and EV charging technologies are developing vigorously. Due to the rapid rate of evolution, industry investors may hesitate to invest in R&D and adopt these new technologies without fully identifying the benefits of investment. An effective incentive measure is to establish a dedicated demonstration area to focus on testing and demonstrating new EV technologies. This measure will promote knowledge exchange and experience sharing between academia and industry, and contribute to the development of new technologies. In addition, this kind of demonstration area also serves as an exhibition, which can promote new EV technological knowledge to the public.

6. Emerging Technologies

6.1. Wireless Charging

The principle of wireless charging for EVs is similar to that of mobile phone wireless charging, albeit on a larger scale. The magnetic coil in the wireless charger transmits the electric energy to another noncontacting magnetic coil installed in the EV. The drivers' job is to park the vehicle in the correct position, aligning the coils and then triggering the charging [43]. Wireless transmission of electricity was firstly proposed in 1904 by Nikola Tesla, who invented the "world system" to "transmit electric energy without wires" using capacitive coupling technology. From then on, a variety of wireless charging technologies have been proposed; for example, magnetic resonance coupling [44], inductive coupling [45], laser radiation [46], and microwave [47]. Inductive charging generates an alternating current electromagnetic field by adopting an induction coil on the charging substrate, and another induction coil in a vehicle absorbs energy from the electromagnetic field to convert it to electric current to charge the battery [48].

As shown in Figure 4a, two induction coils are combined to form the transformer. When magnetic resonance coupling is employed in the inductive charger, the distance between the transmitting coil and receiving coil can be greater [49]. In magnetic resonance coupling, the two copper coils are tuned to resonate at the same natural frequency, and even if the coils are separated by a few feet, one coil connected to the current will generate a magnetic field that makes the second coil resonate [50]. Magnetic resonance causes the electrical energy to be transferred from the transmitting coil to the receiving coil through the air. The current passing through the wires generates an oscillating magnetic field, similar to how a large power plant generates alternating currents through the rotation of a coil between magnets. The magnetic field causes electron oscillation in the nearby coil so that energy is transmitted wirelessly. In 2017, the Hong Kong Productivity Council (HKPC) developed a wireless EV charger as shown in Figure 4b. The system employs magnetic resonance coupling technology with a charging output power of 7 kW with the SAE standard.

Figure 4. Demonstration of wireless charging technologies: (a) resonance inductive coupling in the wireless power transfer system, own elaboration based on [51]; (b) wireless EV charger developed by HKPC; (c) stationary wireless charging parking lots and dynamic charging, reproduced from [52] with permission.

If the resonance frequencies of the two magnetic coils are tuned to be the same to achieve effective wireless charging, the transmission efficiency can be further improved to create high efficiency in a larger gap. When the specially designed energy supply and receiving ends have the same magnetic resonance frequency and working frequency in the MHz frequency band, magnetic resonance coupling occurs. Magnetic resonance coupling can wirelessly transmit 3 to 7 kilowatts of electricity to vehicles parked in a garage or running on the street [44]. A conceptual parking lot with stationary wireless charging facilities is presented in Block 1 of Figure 4c. The wireless charging technology provides great convenience to vehicle owners, and even allows vehicles to charge safely in hazardous environments where grease, dust, or corrosion can compromise electrical contacts or create potential electrical sparks [53,54].

Wireless charging technology also increases the durability of an EV because direct electrical contacts are not required [43]. It is estimated that from 2020 to 2025, the global wireless charging market for EVs will have an annual growth rate of ~50%, and the market will reach USD 70.948 billion by 2025. The predicted growth is mainly attributed to government subsidies and the continuous maturity of the technology. In addition, a new concept of dynamic charging has been proposed; that is, charging EVs stopping at red lights or even driving with the aid of charging coils installed under the road [55,56], as illustrated in Block 2 of Figure 4c.

6.2. Smart Power Distribution

Effective power distribution can meet EV charging needs without major upgrades to the power infrastructure. The proper power delivery system can dynamically adjust electrical power among multiple EV charging facilities, eliminating the need to install additional capacity to meet the growing demand [57]. A dynamic EV charging power control system is shown in Figure 5a. The goal is to dynamically regulate the charging electricity of EVs in accordance with the electrical load of the buildings in order to maximize the power utilization rate. According to the literature [58], the distribution system can also individually adjust the supplied power for each EV based on the demanding power in order to make full use of the power and facilitate the construction of EV chargers. In fact, the amount of EV chargers in a building is restricted by the installed generating capacity. Although the capacity can be expanded by installing power transformers, there are still space constraints in the typically crowded buildings in Hong Kong. As described in the literature [59,60], the dynamic charging strategy and system can analyze the past and real-time electrical load information of buildings, public parking plots, etc.; predict the maximum available charging power of EVs at a certain time and place; and continuously adjust the implementation power of each charger. A dynamic and quick-charging facility for EVs called “Charging Pro” has been developed by the local R&D institution HKPC to provide partial solutions to the EV charging problem in Hong Kong.

Figure 5. Demonstration of smart power distribution technologies: (a) dynamic EV charging power control system, reproduced from [61] with permission; (b) photograph of “Charging Pro”.

The combination of renewable energies and second-life batteries is an emerging trend in EV charging. Renewable energy is green and pollution-free, and when production exceeds demand, the excess capacity can be transferred to the grid. A second-life battery can be integrated into the power system as an energy buffer and as an emergency energy source when the grid is disconnected [62]. A greater number of EVs would have a huge impact on the peak demand in urban power grids. Generally, the peak charging time of EVs is at night, which is opposite to the use of electricity by offices and factories [63]. However, uncoordinated use of electricity may lead to grid congestion, resulting in drops in peak power and voltage. Upgrading the grid requires a lot of money, but by implementing reasonable EV charging management strategies, these problems can be overcome, and the power grid and power generation facilities can be better utilized. In the United Kingdom, by 2050, at least 30% of the low-voltage power grid will be upgraded to meet the charging demand by EVs, equivalent to an estimated investment of EUR 2.4 billion. On the other hand, with the help of smart power-distribution systems, some power grids can meet the EV charging needs without the need to upgrade [64]. All in all, the utilization of smart dynamic power-distribution systems is necessary for photovoltaic devices, EV chargers, and smart buildings.

6.3. Vehicle-to-Home (V2H) and Vehicle-to-Grid (V2G) Systems

Vehicle-to-home (V2H) and vehicle-to-grid (V2G) systems provide managed two-way current flow between the grid and vehicles, and the electricity flows from the grid to the vehicle to complete the charging of the EV batteries. V2H uses the energy stored in EVs to power household appliances, while V2G allows the energy stored in EVs to be released to the grid. The V2H/V2G systems are mainly composed of EVs and battery-management systems (BMSs), in addition to communication technologies that coordinate the bidirectional flow of currents between the vehicles and grid operators.

The V2G concept is shown in Figure 6a. In the standard connection between EVs and the power grid, currents flow from the power grid to the EVs to charge the EV batteries. Realization of V2G requires specially designed communication technologies and algorithms to sense the status of the power grid, determine when the EVs should supply power to the power grid, determine the location and power status of the EVs that intend to provide services, and monitor the charging and discharging process of the EVs in real time [65,66]. Hence, EVs can be used not only as a means of transportation, but also as large-capacity energy-storage devices. The comparison of power consumption with and without a V2G system is shown in Figure 6b,c. With the help of the V2H system, EV owners can charge EVs using solar energy during the day or conventional electricity during off-grid peak hours to save costs, and then use EVs to power their homes or sell electricity to the grid during night peak hours [67,68]. EVs can also be used as emergency backup power sources during power outages [69]. If most EVs in the city are charged during off-peak hours and supply power to the grid during peak hours with the aid of V2G, the peak power consumption of the grid and changes between the peak and off-peak periods can be reduced, thus saving energy and stabilizing the grid.

With the development of V2H/V2G systems, the higher cost of bidirectional chargers can be offset by the benefits of bidirectional charging. V2H/V2G users can make money by returning energy to the grid, save money by leveraging differential energy tariffs, and become energy self-sufficient by connecting to onsite renewables [72]. EV owners with bidirectional chargers can make money by selling the excess energy in the EV batteries back to the grid. In countries where electricity prices are different throughout the day, such as Spain, or countries with preferential off-peak charging tariffs, such as the UK, EV owners can charge EVs during cheap off-peak periods, and sell the excess electricity to the grid during peak periods when electricity prices are more expensive. According to preliminary estimates, the potential income that an EV may bring to its owner through V2G is about EUR 400 per year. In the life cycle of an EV, the average potential income of V2G is estimated to be around EUR 3700. In the frequency regulation market, EVs help

their owners make more money. For example, the Nuve Corporation, a leading V2G pilot project, is currently testing the frequency regulation market for 30 EVs in Denmark, and it is estimated that each EV owner could earn EUR 9000 over the life of the EV. Some energy companies are offering off-peak or “differential” energy tariffs, which means that the price for EV owners to use electricity from the grid at night is much cheaper than during the day. Energy companies use this strategy to balance the grid and ensure that EVs are charged off-peak. If the extra electricity in EVs is used for V2H applications during the day, the electricity bills of EV owners will be greatly reduced. If bidirectional EV charging is combined with renewable energies in the owners’ houses, it will be possible to achieve energy self-sufficiency. For example, the solar panels on the roof can power the house during the day, and the excess energy can be stored in an EV to power. The UK’s Demand Side Response (DSR) program provides homeowners with smart meters that enable them to be self-sufficient through onsite renewable energies, such as wind and solar power. Currently, Europe is promoting V2G/V2H technologies to turn residences and EVs into micro power stations.

Figure 6. Demonstration of V2H and V2G systems: (a) V2G concept, reproduced from [70] with permission; (b,c) variations in power consumption (blue area) with and without a V2G system, reproduced from [71] with permission.

Cooperation is the key to the large-scale development of V2G/V2H. Policymakers, energy producers, automakers, and power suppliers should coordinate closely to promote regulations, technologies, and business operations to enable V2G/V2H to be realized in legal, technical, and economic aspects, and to help customers obtain bidirectional chargers at a reasonable price [73]. Moreover, cost barriers can be overcome in the long run through economies of scale. Once all this is achieved, V2G/V2H charging will become a standard operating procedure.

6.4. Connected Vehicles

The Internet is omnipresent in modern societies and the concept of “connected vehicles” (CVs), also called the “Internet of vehicles” (IoV), has received more attention. CVs are realized by intravehicle connections, intervehicle connections, and automobile mobile Internet. The essence of CVs is a distributed network with wireless mobile communication and information exchange functions by “V2X”, where “X” can represent the roads, vehicles, people, traffic facilities, or other networks [74]. The V2X information exchange is carried out through correspondence protocols and data standards, such as the Standard IEEE 802.11p WAVE and cellular networks. CVs can support intelligent traffic management, intelligent vehicle control, and intelligent dynamic information services, as a typical application of Internet of Things (IoT) technology in intelligent transportation systems (ITS) [75,76]. CVs are connected to the internet by cellular technologies (such as HSDPA, GSM, and LTE telecommunications), 5G networks, Bluetooth, and other short-distance communications technologies [77], as shown in Figure 7. By connecting to the Internet, the vehicle can communicate with the cloud system to obtain services such as navigation, traffic forecasting, and automatic emergency calls. The core of CVs is the gateway with global vehicle identity (GVID) for global vehicular communication, which is operated from a remote integrated terminal [78]. It is also a smart vehicle sensor with global positioning and online recognition functions. The GID terminal integrates the network, smart vehicle sensor, and online license plate.

Figure 7. Schematic diagram of CVs, reproduced from [79] with permission.

6.5. Self-Driving Vehicles

Self-driving vehicles can automatically detect the surrounding environment and maneuver without human intervention. Methods of detecting the surroundings include ultrasound [80], odometry [81], computer vision [82], radar [83], LIDAR [84], and GPS [85], as shown in Figure 8. With the aid of these advanced technologies to detect the surroundings, the control system in a self-driving vehicle interprets the information to identify the optimal path to navigate obstacles and road signs. A control system that can distinguish other vehicles on the road is a must. Generally speaking, a self-driving system creates and maintains an internal map of the surroundings. The information is processed by soft-

ware to identify the driving path, and then instructions are sent to the actuators to control acceleration, deceleration, braking, and steering. Techniques such as obstacle avoidance algorithms, hard-coded rules, prediction models, and intelligent object recognition (e.g., recognizing the difference between bicycles and motorcycles) allow unmanned vehicles to follow traffic rules and bypass obstacles [86,87].

Figure 8. Typical methods of detecting the surroundings, reproduced from [88] with permission.

Some semiautonomous systems require human intervention when encountering extreme uncertainty, while fully self-driving vehicles may not even require aiming circles. Self-driving vehicles can also be categorized as “connected” and “unconnected”, depending on whether they are capable of communicating with other vehicles or transportation facilities. At present, it has been reported that most prototypes do not have the capability of network communication [89]. Telematics, which stands for “telecommunication” and “informatics”, refers to the combination of information and communication technologies for telecommunication used for sending, receiving, and storing information related to remote objects (such as vehicles) via telecommunication equipment involving GPS and navigation systems [90,91]. Furthermore, insurance companies can use telematics to record vehicle status in real time, predict the risk of accidents, and activate automatic safety functions when necessary. Telematics for self-driving vehicles include cellular networks (e.g., 4G Long Term Evolution or 5G wireless networks) and global navigation satellite systems (GNSS) (e.g., US GPS, European Galileo, Chinese BeiDou, or Russian GLONASS systems) [74,91]. Self-driving vehicles can obtain the geographical location and traffic conditions accurately and in real time through GNSS and cloud systems, so as to obtain the optimal route to a destination.

6.6. Benefits of Technological Advance

The rapid development of emerging EV technologies provides new opportunities for the popularization of EVs in Hong Kong. Compared with traditional diesel vehicles, the new vehicle technologies can be deeply integrated with EVs, thus triggering customers’ desire to purchase EVs. The advancement of EV charging technologies facilitates the commercialization of EVs. Fixed wireless charging systems will become an important contributor to the EV charging market. The development of fixed wireless charging systems can facilitate EV charging in parking lots and public places, greatly promoting the development of EV charging networks. In addition, wireless charging is easy to automate, and complements self-driving technology. It is the basic setting for the realization of future automatic parking and automatic charging prospects. The early users of wireless charging will be mainly commercial EVs, such as e-buses, e-trucks, and e-taxis, because wireless

charging provides fast supplementary charging and extends the mileage, which will help solve the problem of insufficient electrification of commercial vehicles in Hong Kong. The residential wireless charging system prevents cables from taking up parking space, which is very attractive for space-strapped Hong Kong buildings. In addition, a wireless charging system, as shown in Block 2 of Figure 4c, laid along the way will greatly increase the range of EVs and solve the problem of “range anxiety” among Hong Kong users.

The rapid growth of the number of EVs in Hong Kong will inevitably put pressure on the power grid. Smart power distribution and V2G/V2H systems can alleviate the power supply problem of crowded high-rise residential buildings in Hong Kong. At the same time, a large number of EVs can also balance the instantaneous power consumption peaks in the building and stabilize the power grid in severe weather such as typhoons to ensure a stable and reliable power supply. At present, the risk of grid overload caused by the rapid spread of EVs is one of the government’s most worrying issues. V2G technology can help ease the burden on Hong Kong’s power grid and avoid expensive grid infrastructure upgrades. The development of smart grids accompanied by EV popularity will also promote Hong Kong’s utilization of abundant local interstitial energy such as wind and solar energy, and promote sustainable social development.

The V2X technology will greatly improve traffic safety through vehicle-to-vehicle and vehicle-to-road unit communications, and alleviate traffic congestion in Hong Kong, which is extremely attractive to various stakeholders, especially citizens. At present, Tesla’s self-driving cars can already run smoothly on highways and other roads without complex obstacles; however, in the densely populated urban areas of Hong Kong, it is still difficult for self-driving vehicles to drive safely. With the help of 5G networks and V2X technology, autonomous driving in urban areas is expected to be realized. V2X technology can track the location of vehicles, which helps prevent vehicle theft and remotely identify vehicles, significantly attracting customers. In addition, V2X technology will simplify the process of settling claims between vehicle owners and insurance companies.

The Hong Kong government can provide financial incentives and testing platforms to charging service providers, power companies, property management offices, telecommunication providers, shared data platforms, R&D institutions, universities, vehicle owners, and so on to designate a blueprint for the local development of emerging EV-related technologies. To expedite the development and commercialization of new technologies, the approval process should be simplified, and private and foreign investment should be encouraged. Under the leadership of the government, deployment of 5G networks should be accelerated to facilitate data sharing, supporting the growth of V2X and self-driving.

7. Decommissioning of Batteries and EVs

7.1. Recycling of EV Accessories

EVs still contain many useful parts after they are decommissioned. Lithium-ion (Li-ion) batteries are the costliest components in EVs and have the greatest value for recycling [92,93]. Other vehicle accessories such as plastic bumpers, tires, metal bodies, and motors can also be recycled. Ease of disassembly must be considered to facilitate recycling, and in fact, the convenience of recycling after decommissioning has been considered when some EVs are produced [94,95]. Recycling companies need to dismantle the vehicle and sort the parts according to the materials prior to crushing for further recycling.

7.2. Battery Recycling

The first-generation EVs are mainly hybrid vehicles, and their batteries are mostly nickel–metal hydride (NiMH) batteries. The service life of NiMH batteries of the first generation of EVs is nearing the end, and the end of life of Li-ion batteries for second-generation EVs will also come. Valuable metals such as Ni, Co, Al, and Li in NiMH batteries and Li-ion batteries can be sorted and recycled [96,97]. In order to recover useful metals from Li-ion batteries, recycling companies usually need to disassemble battery parts and grind them into powder. The materials are first sorted by physical processes and then

chemically treated, for example, by using pyrometallurgical [98], hydrometallurgical [99], or biometallurgical technologies [100] to extract the rare metals. The general waste-battery recycling process is shown in Figure 9. We noted that the recycling technology for Li-ion batteries still needs improvement, which was also claimed in Lv et al.'s review.

Figure 9. Second-life batteries.

7.3. Second-Life Batteries

EVs have a high demand for battery performance. The battery should be replaced when the capacity drops to 70–80% of the initial value, depending on different standards [101–103]. However, the decommissioned battery from EVs still has some charging–discharging cycles for energy-storage applications. The second-life application can extend the life cycle of batteries to benefit solar and wind energy storage, UPS power supply, and so on [104,105]. Before the battery is used, it is necessary to check the health of the battery with the corresponding battery management system (BMS) [106]. Inspection and classification of decommissioned batteries should be standardized to match the designed second-life application. The health of batteries depends on the substances they have been in contact with and the treatment during service. The health of the battery pack depends on the health of each battery module, and the health of each battery module depends on the health of the individual battery cell. Second-life applications of EV batteries require standardized analysis of the battery quality and corresponding procedures to ensure safety.

Second-life batteries constitute a new concept, and the relevant technology and business model are still being explored. Although second-life batteries have a large market potential, the application faces many challenges, including:

- Difficulties in accurately determining the chemical composition of individual batteries;
- Lack of industry standards for safe disassembly of battery packages;
- Lack of detailed information and expertise on battery-specific electronics;
- Fluctuation of the metal contents in the battery and the price of recycled metals.

Recycling companies and vehicle manufacturers should jointly improve the developing second-life battery industry. Using models to collect and classify battery packs can minimize the workload of identifying different battery components. The US commercial standard UL 1974 has already been established to guide the development of second-life battery applications. China has also formulated four national standards (specifically GB/T33598-2017, GB/T34013-2017, GB/T34014-2017, and GB/T34015-2017) to regulate the dismantling of EV batteries, standardize battery codes during manufacturing, track battery usage history, standardize battery pack size, and standardize inspection steps for decommissioned batteries in order to promote their second-life applications. The state of charge (SOC) and state of health (SOH) of batteries can be checked based on these criteria.

The design of business models of different EV stakeholders can facilitate second-life battery application. The business models of second-life batteries can be classified into three categories, namely the standard business model (BM), collaborative BM, and integrative BM [107–109]. The key stakeholder in the energy sector that provides the final solution to the end customers can be called the “solution provider”. The three categories correspond to the different relationships between cross-departmental stakeholders, which are the pure supplier–customer relationship, collaboration relationship, and full integration of solution provider within the original equipment manufacturer (OEM), as shown in Figure 10. The integration degree enhances from standard BM to collaborative BM and further to integrative BM. The collaborative BM can be subdivided into three subcategories based on the integration degree and relative dominance of stakeholders in the development of the final solution.

Figure 10. Schematic typology of second-life battery business models. Own elaboration based on [107].

Since second-life batteries are used products, the BM plays a significant role in their business. A good BM can help second-life battery applications overcome cost disadvantages. Many case studies show that customers do not care about whether the batteries are new or old; they only care about whether the batteries can provide satisfactory power or capacity services [107]. The traditional logic of “buying and selling” may no longer apply to second-life batteries. Second-life battery service providers should pay more attention to the solutions to customer needs rather than simply selling batteries. In the early stage of the development of second-life batteries, solution providers can provide energy-storage services without selling any physical products. In this case, customers do not care if the batteries are old or new, since they do not own battery assets. However, whether the batteries can provide satisfactory solutions to customers is more important. It reduces the risk for customers, and makes it easier and faster for second-life batteries to enter the market. In addition to selling batteries, the OEMs can also provide consulting services and benefit from these consulting services. If the OEMs provide energy-storage services instead of selling physical products, and the solution providers are in charge of finding suitable customers and delivering the final solution to the customers, then stakeholders can continuously obtain value from the batteries during their entire second-life cycle by meeting the diversified market demand for batteries, as claimed in [107,108].

Economic efficiency is the key to the commercialization of EV second-life battery applications. At present, the cheaper price of second-life batteries compared to that of new batteries is the main driving force for many companies to develop a second-life battery business. However, with the advancement of battery technologies, the ever-decreasing

price of new batteries will be one of the main challenges for second-life battery applications. In order to ensure the attractiveness of the low cost of second-life batteries, the OEMs are actively developing methods to reduce the cost of second-life battery applications, such as directly utilization of the entire decommissioned battery pack, to avoid the cost of dismantling the battery pack. In addition, the initial design of batteries has a great influence on their reuse. At present, EV OEMs only consider vehicle application when designing and preparing batteries. If the BMS does not accurately collect the usage data and SOH of the EV batteries, the retired EV batteries must be handed over to a third party for testing, which adds additional transportation and testing costs. In addition, if the accessories of batteries, such as the BMS, do not match with other secondary applications, extra costs will be required to customize the new BMS. Naturally, the OEMs prioritize optimizing the batteries' first lifespan. However, if the OEMs actively cooperate with battery refurbishers, second-life battery customers, and battery recyclers from the beginning, it would be possible to simplify the batteries' second-life application and recycling processes, allowing OEMs to profit by participating in the entire value chain of batteries [110]. The cooperation of the entire value chain will make the health data and material composition of batteries more transparent throughout the whole life cycle so that every stakeholder can realize the greatest benefit.

In terms of policy, policymakers should fully understand the value of second-life batteries in the energy market, and treat battery storage in the same way as other storage and power-generation businesses to support the development of future smart grids. At present, in most markets, only subsidies for new batteries exist, and there are no subsidies for second-life batteries [107]. Second-life batteries should be included in the scope of subsidies as soon as possible to promote their healthy development. In the future mature stage of the battery market, policymakers can also regulate the price of battery raw materials to maintain the price advantage of second-life batteries, to maintain the sustainable development of society.

7.4. Global Status of Battery Recycling and Second-Life Applications

North America: The international collaboration organization between Canada, Mexico, and the United States, called Commission for Environmental Cooperation (CEC), has been actively promoting EVs in the North American region. In the past 10 years, the North American EV market has grown substantially, and the number of decommissioned EV batteries is expected to increase continually. The major enterprises in North America with technologies for recycling EV batteries include Inmetco, Retrieve, RMC, and Glencore/Xstrata. The above-mentioned UL 1974 standard for second-life battery applications may be upgraded and developed into a US national standard to guide the safety and performance testing of secondary life batteries.

Europe: Europe leads the world in battery recycling legislation. In 1991, the European Battery Directive issued clear targets for the collection and recycling of various types of batteries. The Belgian enterprise Umicore has already carried out many battery recycling projects in Europe. SNAM, located in France, recycles more than 300 tons of decommissioned Li-ion batteries each year. Another French company, EuroDieuze Industrie, specializes in the recycling of batteries and lithium, and Recupyl in France uses hydrometallurgical processes to treat waste batteries. European solar grid parity has been basically achieved. Recycling companies can repackage the decommissioned batteries for use in residential solar storage systems, and in addition to integration with photovoltaic systems, decommissioned batteries can be integrated with industrial sectors or winnowers to store wind energy [111].

Japan: A joint venture of Nissan and Sumitomo, called 4R ENERGY, has been established to specialize in the development and testing of second-life applications of decommissioned Li-ion batteries. The name "4R ENERGY" means "reuse, remanufacture, resell, and recycle". The goal is to increase the use of renewable energy to improve sustainability and improve the value chain in the global market. In addition, Sumitomo Metal Mining (SMM) cooperates with Toyota to recycle NiMH batteries after decommissioning hybrid vehicles.

Honda obtained a license for the recycling of EV batteries in the Japanese market in 2017, and is developing a new process to extract rare earth metal oxides from NiMH batteries in cooperation with Japan Metal and Chemicals (JMC).

Mainland China: China has the largest number of EVs in the world, and recycling of decommissioned EV batteries will be a grand challenge in the future. The Chinese government has been actively promoting the reuse and recycling of decommissioned EV batteries, and has issued a series of national GB standards that provide guidance to battery recycling companies to examine decommissioned batteries and package them for second-life applications. Representative enterprises such as GEM, Brunp, CATL, Sound Group, and Technology Highpower have recycled Li-ion batteries commercially. At present, the majority of recycling businesses only focus on extracting valuable metals in waste batteries. A few companies have begun to develop second-life battery applications. OptimumNano, for example, is trying to construct a 3 MW energy-storage grid using decommissioned EV batteries.

Hong Kong: Reuse and recycling of decommissioned batteries are also highly regarded in Hong Kong. According to the “Waste Disposal (Chemical Waste) (General) Regulations” of the Environmental Protection Department, battery recycling enterprises must obtain chemical waste collection permits and comply with the relevant regulations on collecting, sorting, storage, packaging, labeling, and transportation. Currently, there are only four local companies that are licensed to dispose of decommissioned batteries from EVs. However, due to the lack of land in Hong Kong to build large chemical waste recycling and treatment facilities, decommissioned battery-collecting companies can only send the collected batteries to mainland China, Japan, Singapore, South Korea, and other places for further processing. Nonetheless, Hong Kong should focus on developing and promoting second-life battery applications for sustainable development.

8. Conclusions

EVs boasting zero emissions reduce air pollution, leading to sustainable development. In this study, EV adoption in Hong Kong, global EV markets, the present status of EVs in Hong Kong, EV adoption challenges and development in Hong Kong, strategies for EV promotion, emerging technologies, and decommissioning of batteries and EVs were discussed. The major global EV markets include Norway, the Netherlands, Sweden, France, the United Kingdom, the United States, and China, and many countries plan to ban ICEVs in the next 10 to 20 years. The growth rate of EVs in Hong Kong is high, although the proportion is still low. In addition, the adoption of commercial EVs is less than that of private cars, and this situation must improve. The challenges facing private electric cars include insufficient charging infrastructures, inadequate management of public charging facilities, and difficult repair and maintenance, while the problems for commercial EVs are insufficient parking places and charging infrastructures, “dead mileage” during charging, long charging times, and limited commercial models. The use of EVs in Hong Kong can be promoted by strategies such as providing incentives and bonuses for commercial EVs, offering high-power quick-charging facilities, actively developing commercial EVs, installing more charging infrastructures for private EVs, building connections among stakeholders, encouraging the participation of the private sector to promote fee-based services, and supporting the development of innovative technologies. Emerging EV technologies include wireless charging, smart power distribution, V2H and V2G systems, connected vehicles, and self-driving. Eco-friendly decommissioning of batteries and EVs is also important in order to facilitate EV accessory recycling, battery recycling, and second-life battery applications. This review serves as a reference and guide for the sustainable and smart evolution of the transportation sector in Hong Kong and offers perspectives and recommendations on both green transportation and the burgeoning smart mobility sector in Hong Kong and other worldwide major cities.

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