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The Chinese plug-in electric vehicles industry in post-COVID-19 era towards 2035: Where is the path to revival?

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**ABSTRACT**

The sudden Coronavirus Disease reported at the end of 2019 (COVID-19) has brought huge pressure to Chinese Plug-in Electric Vehicles (PEVs) industry which is bearing heavy burden under the decreasing fiscal subsidy. If the epidemic continues to rage as the worst case, analysis based on System Dynamics Model (SDM) indicates that the whole PEVs industry in China may shrink by half compared with its originally expected level in 2035. To emerge from the recession, feasible industrial policies include (1) accelerating the construction of charging infrastructures, (2) mitigating the downtrend of financial assistance and (3) providing more traffic privilege for drivers. Extending the deadline of fiscal subsidy by only 2 years, which has been adopted by the Chinese central government, is demonstrated to achieve remarkable effect for the revival of PEVs market. By contrast, the time when providing best charging service or most traffic privilege to get the PEVs industry back to normal needs to be advanced by 10 years or earlier. For industrial policy makers, actively implementing the other two promoting measures on the basis of existing monetary support may be a more efficient strategy for Chinese PEVs market to revive from the shadow in post-COVID-19 era.

**1. Introduction**

The sustainability of resources has always been a hot area of research (Zhang et al., 2017; Hu et al., 2018). Road transportation contributes a huge amount of petroleum consumption (Quan et al., 2020) and carbon emission (Setiawan, 2019). It is a prime battleground on the approach to sustainable development. Plug-in Electric Vehicles (PEVs), which are given great expectations in reducing the discharge of environmental pollutants as well as greenhouse gases (GHGs) and extending the available period of oil resource (Hardman, 2019), have been extensively promoted all over the world (Hao et al., 2020). A well-to-wheels analysis reveals that PEVs have potential to reduce GHGs in three Canadian provinces with different grid types and emissions intensities (Kamiya et al., 2019). The fueling and maintenance costs of PEVs are lower than Internal Combustion Engine Vehicles (ICEVs), which means that after deploying PEVs it will bring not only environmental but also transportation justice for communities. Low-income consumers from California in America are encouraged to get access to PEVs (Canepa et al., 2019). The state also requires a certain percentage of zero emission vehicles to be sold in light-duty vehicles and PEVs are preferred by automakers to attain this goal (Ou et al., 2019). In Europe, radical proposals have been extensively put forward. For instance, Poland plans to develop one million electric cars in 2025 (Łuszczak et al., 2021). Some Asian countries have deemed PEVs as a practical instrument to manage with the enormous stress from population, resource and environment as well. Fig. 1 shows the possible schedule when ICEVs will be expelled from the market in several countries or regions. At the corporate level, previously relatively conservative attitude has been transformed to investment projects which have already been under way. Mainstream vehicle manufacturers have actively responded and released a variety of PEVs into the American market to attract customers since 2010 (Carley et al., 2019a). Getting rid of the dependence on fossil resources and striving to achieve zero emission of environmental pollutants as well as GHGs is turning into a broad consensus within the context of sustainable development globally. There is a good chance that PEVs will occupy a substantial proportion over the next decades. For industrial policy makers, a thorough analysis revolving around the penetration of PEVs will make a contribution to leading the electrification revolution in auto
industry (Melton et al., 2020) and exploring the effect of consequent decarbonization in road traffic more effectively.

Unfortunately, the outbreak of Coronavirus Disease reported at the end of 2019 (COVID-19) has impacted the whole of humanity (Oldkop et al., 2020). The sudden catastrophe is posing formidable challenges to every walk of life and has grown into a historic crisis. For the sake of restraining the epidemic from transmitting as early as possible, some affected states have to take strict controls (Depellegrin et al., 2020; Braga et al., 2020) such as stopping public transport (Chen et al., 2021), suspending classes (Sicard et al., 2020) or shutting down factories to reduce the gathering and flowing of crowds and thus further cut off the route of large-scale communication. People are encouraged to finish their work, shop and attend large conferences online at home as much as possible. The chain reaction is huge unemployment, insolvencies, empty tourist spots, shrinking consumption, deferring new projects and collapsing confidence of the capital. Hence the society has unprecedentedly stalled. Although governments are trying all possible means to revive the economy like digging deep into its pocket (Hanna et al., 2020), the situation may still be pessimistic before the adverse impact is completely eliminated.

So, it is desperately necessary for the government to assess the comprehensive outcome arising from this "Black Swan incident" so as to make adequate preparation for the market movement in the post-COVID-19 era. With the technical accumulation over the years, the competitiveness of PEVs has been increasing significantly. More and more conveniences are provided to attract PEVs purchasers. In the meantime, incentive policy in different countries has also changed in different degrees. What kind of impact will COVID-19 bring to the industry? What countermeasures can be taken by politicians to balance the recession and embrace the revival in post-COVID-19 era? It is self-evident that the industrial policy over the next decades is extremely important. In order to better understand the developmental trend of PEVs industry at the macroscopic level, we have established a System Dynamics Model (SDM) to predict their market demand. It is an integrated model which contains the interaction between the adoption of PEVs and many other influential factors. The following scenario analysis has clearly depicted the variation of PEVs demand brought by altering conditions and specific industrial policies can be selectively designed to treat the possible changes in practice. Besides, there may even be an opportunity for the result of demand forecasting to provide valuable guidance and reference for the sustainable development of the whole industry chain, which deserves further investigation and study.

The remainder of this article is organized as follows: Section 2 introduces the application of SDM through an overview of relevant literature. Section 3 is the detailed structure and operating mechanism of the SDM applied to demonstrating the evolutionary tendency of PEVs. Section 4 presents the impacts on PEVs industry resulting from COVID-19. Section 5 puts forward bailing measures and compares the effects of taking different industrial policies as solutions. The final conclusion and policy implications are displayed in Section 6.

2. Literature review

The SDM is a high-efficiency tool to enhance the comprehension of how a specific socioeconomic system works over time, which can be widely applied to industry, energy, environment and many other areas (Shao and Jin, 2020; Liu et al., 2019; Egilmez and Tatari, 2012). Matthew et al. have established an integrated SDM to simulate the endogenous electricity demand in an isolated island system under low-carbon policies and socio-economic developments (Matthew et al., 2017). Compared with the policies that increase tourism and the expansion of electric vehicles, energy efficient measures are identified to have the greatest extended impact on electricity demand. Varma et al. use SDM to provide sustainable solutions to narrow the gap between electricity demand and supply in future India (Varma and Sushil, 2019). Policy makers should push the transition to renewable electricity adhering to flexibility, bankability and a long-term vision for sustainability. The strongest motivation of innovation in road transport is partly derived from energy conservation and emission reduction. The SDM has been frequently employed in discussing the environmental and resource benefits of these new emerging fleets. UniSyD_JP, a Japanese multi-regional partial equilibrium SDM, is adopted by Watabe et al. to explore the effects brought by low emissions vehicles on cutting down greenhouse gas emissions in Japan from 2016 to 2060 (Watabe et al., 2019). Both the development of infrastructure and high carbon taxes are needed to bring remarkable emissions reduction. Kamal et al. have examined the impacts of vehicular composition and turnover rate on Qatari energy consumption patterns based on the combination of SDM and vehicle cohort modeling (Kamal et al., 2020). The development of alternate fuel vehicles in vehicle-importing countries need new regulations, laws and supporting infrastructures. The source of energy production is an important element and electricity generated by natural gas for electric cars would add additional emission of CO2. Pillay et al. have studied the effects of the market penetration rate of electric vehicles on carbon emissions in South Africa (Pillay et al., 2020). For eCars and eBuses, the result of reducing carbon emissions depends on the practical volumes and the source of electricity supply, respectively. Zheng et al. evaluate the effect of energy-saving and emission-reducing in China due to the development of electric vehicles in virtue of a SDM (Zheng et al., 2019). The expected impacts will vary according to several factors such as the integral progress of electric vehicles, the decarbonization in power sector and the improvement of electric vehicles and internal

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Fig. 1. The possible prohibiting year of ICEVs in different countries or regions.
combustion engine vehicles in technology. The sharing economy is an emerging business model and VAMO is the first e-sharing scheme in Brazil. Luna et al. have discussed its effect on carbon emissions and electric vehicle adoption based on SDM (Luna et al., 2020). Compared with the business-as-usual scenario, 29% CO₂ and 36% electric vehicle adoption can be reduced and increased under the combination of retired policy and VAMO incentive policy, respectively. To explore the approach and feasibility of accomplishing a carbon-neutral transport sector in Iceland by 2050, Shafiei et al. conduct a comparative analysis of three transition pathways on the basis of SDM (Shafiei et al., 2017). The electricity trajectory is verified to be the cheapest pathway but has a lower potential in the mitigation of GHG.

In terms of the green vehicles themselves, the SDM has also been generally utilized in a series of researches about their diffusion, supporting facilities or relevant services. SDM is utilized by Liu et al. to confirm the critical factors that affected the electric vehicle charging station allocation from the conduction mechanism (Liu et al., 2019). Oliveira et al. build a SDM to discuss the diffusion of alternative fuel vehicles in Portugal taking into account dynamic preferences (Oliveira et al., 2019). Considering dynamic preferences is proven conducive to the accuracy of prediction and policy makers can accordingly make adjustments to boost the adoption of alternative fuel vehicles. A SDM has been utilized by Benvenutti et al. to discuss the influence of public policies from Brazilian government on the long-term diffusion dynamics of alternative fuel vehicles (Benvenutti et al., 2017). The advancement of renewable energy technologies applied in transportation sector will rely on reinforcing efforts and may need a far-sighted consideration. Harrison et al. have employed a SDM to investigate the potential of e-mobility in the European Union and pointed out that the competition between electrical powertrain options is noteworthy (Harrison et al., 2018). Zhang et al. develop a charge pricing model based on SDM and charge operators can consequently obtain a charge price which was appropriate for both electric vehicle users and themselves (Zhang et al., 2018a). The feasible charge price depends on operating cost, electricity price and charge volume. Corresponding measures involved in these respects can be taken for mutual benefits. Liu et al. have conducted a scenario analysis based on SDM to discuss the future of electric vehicles under policy stimulations in China (Liu and Xiao, 2018). The price and demand of electric vehicles are profoundly affected by financial support from the Chinese government.

Promoting electric road transport may be a quite systematic program which needs to consider various conditions including supply, demand and supporting infrastructure (I. uszczek et al., 2021). While SDM is a representative solution when handling the ever-changing interaction within a certain range. The impact from COVID-19 on PEVs industry may have a high degree of uncertainty. In view of the successful applications above, it is suitable to choose SDM as the primary instrument to perform the predicting task and give pragmatic suggestions based on subsequent scenario analysis. Vensim is a common software of operating SDM and it has undertaken the main analytic work in this paper.

3. Methodology

3.1. System boundary

China has expanded into the largest market of PEVs (Helveston et al., 2019). As part of the national development strategies (Sun and Wang, 2018), there is no doubt that pushing the adoption of new energy vehicles has been endowed with profound consequence in this country. Suffering the double shock of falling subsidy and COVID-19, special attention has been focused on the trend of Chinese market more than ever. The administration has expressed the hope that its native technology in new energy vehicles manufacturing industry can reach a new height in 2025. The Ministry of Industry and Information Technology posted an exposure draft called the "Development Plan of New Energy Automobile Industry (2021–2035)" at the end of 2019 in its website. It is another weighty instruction after the announcement of "Development Plan of Fuel-Efficient and New Energy Automobile Industry (2012–2020)" in mid-2012 by the Chinese State Council online. 2035 is evidently recognized as another key node at the timeline through the roadmap of PEVs. At that time, BEVs are expected to become the mainstream in market while electrification is expected to be fully accomplished in the public sphere. It may be a significant point when broader electrification will be started in the domain of road transport. Thus, we decide to define the PEVs market in China from 2015 to 2035 as the system boundary to offer a proactive understanding towards the hot issues in the future revolution of road traffic.

3.2. Model structure

The diffusion of PEVs appears in both the sector of Passenger Vehicles (PVs) and Commercial Vehicles (CVs). PVs and CVs have different service objects and working occasions. There also exists a large gap between the market demand of them in practice. So, the spread of electric vehicles usually exhibits different rules within these two realms. PEVs generally consist of two technical routes: Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs) (Krause et al., 2013; Khan and Kockelman, 2012; Assen et al., 2015). Although BEVs have acquired recognition from some user groups like the early adopters or innovators so far, wider acceptance may be further achieved in broader population (Daramy-Williams et al., 2019). According to the existing research, range anxiety (Pillay et al., 2019; Wang and Wang, 2007; Xing et al., 2007), price (Feng et al., 2019) and long recharging times (Wager et al., 2016; Carley et al., 2019b) can all have a negative effect on the adoption of BEVs. These knotty problems are partly to be blamed for the depressed BEVs market currently. But what deserves looking forward to is that it will gradually be boomed with the performance improvement of some crucial modules inside. Other influential factors include subsidies (Wang et al., 2019), charging infrastructure (Velandia Vargas et al., 2019; Greene et al., 2020; Chakraborty et al., 2019), traffic policy (Zhuge et al., 2020; Zhang et al., 2018b), the manufacturer’s portfolio decisions (Kieckhaefer et al., 2017) and so on. PHEVs can be powered by both electricity and fuel (Carley et al., 2019a; Samaie et al., 2020; Long et al., 2019). The former is appropriate for short trip while the latter can ensure the requirement of journey far away. Range anxiety is fully alleviated and the drivers’ dependence on external charging facilities is reduced. In the matter of vehicle reliability and residual value (Lei et al., 2020; Guo and Zhou, 2019), PHEVs may also have a closer level with ICEVs from the perspective of customers. Before the property of BEVs is mature enough, they are regarded as a product in the transition from ICEVs to BEVs (Ma et al., 2019) due to the opportune balance between cutting down the tail gas emissions and sufficiently satisfying the travelling desire. If there is a universal drop in price and more support in policy, the market demand of PHEVs is bound to embrace an obvious leap. Besides, PVs and CVs could have been segmented in more details like cars, sport utility vehicles, trucks, buses and so on. However, as a matter of fact, the quantitative estimation of PHEVs has already relied on simplified approach with coefficients due to the unavailability of statistical data. In addition, more parameters involved in the SDM would greatly increase the difficulty of simulating.

In view of the summary above, we have decided to classify PEVs into four groups to juggle the rationality and simplicity. They are PVs-BEV, PVs-PHEV, CVs-BEV and CVs-PHEV. This study is intended to provide response measures for the robust advancement (Keith et al., 2020) of PEVs. The sales of PVs-PHEV and CVs-PHEV are designated to be proportional to the ones of PVs-BEV and CVs-BEV while the coefficient may mutate according to the concrete development status. Only PVs-BEV and CVs-BEV are involved in the specific modelling.

As aforementioned, we have selected the common concerns of potential PEVs owners and sorted them into three dimensions by scope: Capacity Subsystem, Circumstance Subsystem and Cost Subsystem (3C Subsystems). Fig. 2 has displayed the detailed structure of each
Capacity Subsystem
Cruising mileage, charging duration, vehicle reliability and residual value: They are frequently compared with the ones of ICEVs to assess the performance of BEVs.

Circumstance Subsystem
Inventory shares, charging density and traffic priority: Except for vehicle itself, the convenient experience in the process of driving is also very critical. The expanding fleet of BEVs will catch more eyeballs and generate demonstrative effect.

Cost Subsystem
Cost of production and fiscal subsidy: Selling price is a crucial consideration. As the manufacturing expense is lowering, financial support from fiscal subsidy is gradually phased out.

3.3. Model test and scenario setting
After all the parameters are confirmed through repeating adjustments in Vensim, we have conducted accuracy test by simulation runs. Fig. 5 shows a good fitting degree as no relative error has exceeded 10%. Scenario analysis in following sections is built on this reliable model. The detailed source and estimation basis of each item are listed in Table S1, Supplementary Material. Table 1 displays the scenario setting and explanation. The scenario setting of the five auxiliary variables is in the order from left to right. For instance, "a-b-c-d-e" appearing in subsequent discussion means the scenario of charging density, fiscal subsidy, traffic priority, market demand of xvs and electrification motivation are set as a, b, c, d and e in turn. From 5 to 0, the time when fiscal subsidy of xvs and electrification motivation are set as 5, the time required for market demand of xvs to return to the level without COVID-19 gradually extends from 2 to 10 years. In the meantime, the electrification motivation descends by decile. It can serve as a...
universal calculation platform when introducing longer recovery time, lower shares, and different combinations without one-to-one correspondence. By combining different scenarios based on the reality, the evolutionary tendency of PEVs industry is clearly simulated and it has laid the groundwork for further exploration.

4. Implication of COVID-19

As one of the pillars in the national economy of China, automobile industry is inextricably linked with diverse business and trade thus it is badly hit by COVID-19. On the one hand, the pace of electrification has slowed because of the enormous uncertainty from production and research. On the other hand, the ability of consumers is greatly dampened in demand side. Therefore, the impact of COVID-19 is assumed to be reflected at supply and demand side in this research. More detailed supporting information has been provided in Supplementary Material.

4.1. Impact on PVs-PEV

In order to investigate how much influence would be brought by COVID-19 under different situations and the individual effect of supply and demand side, Fig. 6 is the results of scenario and sensitivity analysis about the sales and inventory of PVs-PEV. As is shown in it, the epidemic can lead to an obvious decrease of the two indexes. Before COVID-19 broke out, the sales and inventory of PVs-PEV is expected to reach nearly 20 and over 70 million by 2035. With the extension of time for recovery and further lowering of electrification motivation of PVs, they would drop step by step and the difference between two curves gets closer as well. If COVID-19 makes the most negative effect, the sales and inventory of PVs-PEV would only be 8.5 and 38 million after 15 years. Compared with the original level, the fall percentage is as high as 57% and 48%. That is, both the selling and stock market may shrink by approximately half in 2035. Thus, the government ought to customize practical industrial policy as soon as possible for manufacturer and agency to ride out the storm. Otherwise, the development of PVs-PEV

Table 1

Scenario setting and explanation xvs = pvs or cvs.

| Setting | Scenario | Setting | Scenario |
|---------|----------|---------|----------|
| 1       | 2023 – 1 | 10      | 2023 – 1 |
| 2       | 2025 – 1 | 8       | 2025 – 1 |
| 3       | 2028 – 1 | 6       | 2028 – 1 |
| 4       | 2030 – 1 | 4       | 2030 – 1 |
| 5       | 2032 – 1 | 2       | 2032 – 1 |
| 0       | 2035 – 1 | 0       | 2035 – 1 |
| 0.500/0.250 | 2       | 0.450/0.225 | 4 |
| 0.350/0.175 | 6       | 0.300/0.150 | 8 |
| 0.250/0.125 | 10      |          | 10 |

Fig. 4. The final diagram with stocks and flows (XVs = PVs or CVs xvs = pvs or cvs).

Fig. 5. The relative error between real value and simulation value IPB: Inventory of PVs-BEV spb: sales of pvs-bev ICB: Inventory of CVs-BEV scb: sales of cvs-bev.
would be thrown into the edge of a cliff. Fig. 6 also reveals the sensitivity of impact from

- market demand of PVs and
- electrification motivation. We have discussed their individual influence on the sales and inventory of PVs-PEV. Due to the restriction of COVID-19, both market demand of PVs and electrification motivation would depress, which has been described in Fig. S1 in Supplementary Material. The longer the epidemic lasts, the more difficult it is for them to return to previous level. If the desired development of PVs-BEV stays unchanged while regaining the spending power has to take a decade, only 12.7 and 51.9 million PVs-PEV could be sold and held in 2035, which is cut down by 35% and 29%. Likewise, the faded passion towards announcing upgraded products is able to create a reduction of 33% sales to 13.1 and 27% inventory to 52.9 million solely after 15 years. On the whole, the impact from the variation of market demand of PVs and electrification motivation is roughly equivalent. Without other external distractions, a third of sales and inventory is likely to be lost in 2035 under either of the two destructive influences. In addition, during the simulation we find that the descending of electrification motivation also directly hampers the improvement of critical performances in PVs-BEV. The time when drivers needn’t worry about the cruising mileage of PVs-BEV is delayed for 7 years to 2033. Residual value hasn’t been a problem in 2035 but it may only be 77% of the same standard with ICEVs then. In the meantime, the cost of production and charging duration has increased by up to 37% and 286%, respectively. Vehicle reliability would decrease by 16%.

4.2. Impact on CVs-PEV

The procedure of analysis about CVs-PEV is similar to PVs-PEV. Scenario analysis in Fig. 7 shows that when recovery time rises from 2 to 10 years while prospective developing confidence of PVs-BEV falls from 0.25 to 0.125 (Fig. S1), the sales and inventory of CVs-PEV may be reduced by 58% from 1.2 to 0.5 million and 51% from 5.1 to 2.5 million. In contrast, PVs-PEV would be slightly less affected by COVID-19 than CVs-PEV. It seems that PEVs in commercial sector may need more assistance of all sides from policy to fund. Moreover, most of the gaps between every two curves in Fig. 7 also gets narrower.

The remainder of Fig. 7 is the sensitivity analysis which has demonstrated the sole effect of market demand of CVs and electrification motivation. As the restoring date is repeatedly put off, the sales and inventory of CVs-PEV still remains 1.1 and 4.7 million. In comparison to the former level (1.2 million sales and 5.1 million inventory), both of the downturn is only 8%. However, under the lack of advancing faith, the two indexes would be condensed to 0.5 and 2.7 million. The corresponding contraction is 58% and 42%. It can be seen that for CVs-PEV, the pressure from decreasing electrification motivation is much greater than shrinking market demand of CVs. The distinction is probably attributed to the different functions of PVs and CVs. The majority of CVs-PEV in public domains come from compulsory procurement as required by some specific regulations like buses, official vehicles, road sweepers and delivery vehicles. While in private field customers of CVs are more concerned with the economic benefits of...
PEVs. So, CVs-PEV probably relies more on the \( \circ \)-electrication motivation than \( \odot \)-market demand of cvs. The simulating process also indicates that with the least enthusiasm of electricity driving, it needs 9 extra years for the cruising mileage of CVs-PEV to become mature until 2034. Meanwhile, the cost of production and charging duration has risen by as much as 45% and 352%. Only 82% of vehicle reliability and 66% of residual value which could have achieved the equivalent level to ICEVs by 2035 is planned to be realized then.

5. Feasible coping strategies

On March 31, 2020, the State Council’s executive meeting determined that the original point 2021 when Chinese central government will cancel the financial support is deferred to 2023. The instruction of energy working in 2020 issued by National Energy Administration of China also intends to strengthen the building of charging infrastructures. Charging facility is ushering its spring. Based on the two incentives above along with the requirement of unrestricted purchasing and license plate for new energy vehicles aforementioned, we have formulated three coping strategies: (1) providing more conveniences for charging, (2) mitigating the downturn of financial support and (3) increasing the degree of traffic privilege. The detailed variation tendency of them is depicted in Fig. S2 in Supplementary Material. If COVID-19 continues to impact people’s production and living, the time when \( \circ \)-charging density and \( \odot \)-traffic priority peaking is gradually brought forward from 2035 to 2023. The ending point of \( \odot \)-fiscal subsidy may be delayed by 10 years–2031. We assume the impact of the epidemic is moderate, which signifies that the recovery time of market demand is 6 years while the expected shares PVs-PEV and CVs-PEV would be reduced to 0.35 and 0.175, respectively. The bailing effects are discussed as follows.

Quantitative comparison based on sensitivity analysis could clearly present the reviving capacity among different rescuing policies. Then the superior one with high efficiency would be precisely recognized and preferentially considered for subsequent adoption. Fig. 8 reveals the impact of taking coping strategies on the sales and inventory of PVs-PEV. The recovery rate of sales and inventory of PVs-PEV is the ratio of each value under bailing measures to original one without COVID-19. The pillar is higher than the red line is a sign that the corresponding value has reached the original scale. On the contrary, the requirement would not be met. For sales, if the construction of charging facilities would be finished in 2025 (4-0-0-(-3)-(-3)), there are still half periods that could not restore to previous level. For inventory and lifting traffic priority, the reviving function is less obvious yet. It can also be seen that even the time when \( \circ \)-charging density and \( \odot \)-traffic priority attain the peak value (5-0-0-(-3)-(-3) and 0-0-5-(-3)-(-3)) has been brought forward for 12 years to the earliest 2023, only the recovery effect of inventory of PVs-PEV by providing more charging conveniences is scarcely satisfied. However, extending the deadline of \( \odot \)-fiscal subsidy for 2 years is almost enough to get the market back to normal. If we simultaneously take the three coping strategies by lengthening or advancing for 2 years, the negative impact of COVID-19 might be fully eliminated.

Similar analysis about CVs-PEV is revealed in Fig. 9. The reviving standard is set as 100%, too. No matter how positive the attitude towards increasing \( \circ \)-charging density and \( \odot \)-traffic priority is, the ultimate result could not be totally fulfilling. In the meantime, the maximal recovering proportion of these two measures is only 116% ((5-0-0-(-3)-(-3) for the sales in 2023). Other ratios are difficult to exceed 110%. However, the influence of extending \( \odot \)-fiscal subsidy would be much more significant especially for boosting the sales of CVs-PEV. We can clearly find that it may still need to be advanced by 10 years or earlier when providing best charging convenience or most traffic privilege separately to accomplish the target of rescuing the market. If we select to delay the point when monetary compensation will be ended alone, the required time for revival is shortened to around 4 years. It may be further reduced to few years in case of pitching all the three solutions into work.

The sudden COVID-19 is nothing less than a blockbuster to the global economy. Industrial policy makers around the world are aiming at the same goal of how to bail it out as soon as possible. The automobile industry which has always been intensively concerned is extremely important for the social development. But where is the path to revival? Overly extending the period of financial support may encourage dependency and lead to the waste of monetary resource. We have also demonstrated that only accelerating the construction of auxiliary facility or granting more traffic privilege are not necessarily efficient because the accomplishing time may need to be advanced for more than 10 years in this section. As a matter of fact, the Chinese central government has declared that the fiscal subsidy would be abolished in 2023. According to the excellent performance of PEVs industry in the last two years, it has been proved to be a strong incentive for the market to get rid of the terrible epidemic. The joint application of the three industrial policies is probably the better bailing measure. Industrial policy makers in China can consider taking diversified coping strategies based on the current subsidy policy to balance the negative impact of COVID-19 on PEVs industry. In the face of highly variable developing trend, SDM could play an efficient role in providing practical suggestions to guide the formulation of industrial policy with low cost by sufficient simulating consideration.

6. Conclusion

For the purpose of environmental protection and reserving resources, PEVs have been prompted around the world and China is one of the most...
active participants promoting the sustainable transformation in this area. Unfortunately, the unexpected COVID-19 introduces much uncertainty and even a profound imprint into the whole automotive line. There is an urgent need for Chinese PEVs industry which is suffering tremendous pressure from the descent of fiscal subsidy to get out of the epidemic and carry on harvesting more shares. According to the plan of Chinese government, 2035 is the next vital point in the roadmap. Therefore, we have analyzed the interaction between PEVs and various influential elements in China towards 2035 based on SDM to investigate the impacts brought by COVID-19 and provide effective industrial policies consequently. A comprehensive exploration around COVID-19 under specified conditions has been presented. PVs and CVs are discussed separately while PEVs are further divided into BEVs and PHEVs. The merged SDM which consists of Capacity, Circumstance and Cost Subsystem (3C Subsystems) functions well in Vensim through iterative tests.

The eruption of COVID-19 would directly lead to the contraction of purchasing power and postponement of electrification process. The performance improvement of PEVs is also delayed. To cope with the unprecedented epidemic crisis, the time when charging convenience and traffic privilege reach the maximum can be advanced as early as 2023. The decreasing financial support may have been afforded until 2031. On the basis of scenario analysis, it can be concluded for industrial policy makers as follows:

1. As hypothesized in the worst case, it would take 10 years for the market demand to return to the previous level without COVID-19 while the electrification motivation are halved in 2035. That the latter would have greater impact on CVs-PEV is probably due to its special customers and purpose. The whole PEVs industry may shrink by 50%.
2. Quickening the construction of charging facilities or providing more traffic privilege is effective for the market reviving but the completing time may need to be advanced by 10 years or even earlier to achieve the desired result. Under the same moderate epidemic, extending the ending time of decreasing fiscal subsidy for 2 years is found to have obvious promoting effect for the recovery of PEVs market, which has been adopted by the Chinese central government and proved to be effective.
3. Actively improving the charging density and releasing more traffic priority during driving on the basis of present fiscal subsidy policy may be more efficient for PEVs market in China to revive from the restriction of COVID-19 because financial resource is saved while the bailing effect is more significant. Before the ambitious blueprint of electrification revolution in automotive sector is achieved as scheduled, it still needs to overcome multiple obstacles in post-COVID-19 era.

CRediT authorship contribution statement

Yuchen Hu: Writing – original draft, Writing – review & editing, Conceptualization, Methodology, Data curation, Data collection and calculation, original draft preparation, Original paper reviewing. Shen Qu: Data curation, Writing – original draft, Writing – review & editing, Software, Data collection and calculation, Original paper reviewing, Funding acquisition. Kai Huang: Supervision, Writing – review & editing, Reviewing and Editing, Validation, Funding acquisition. Bingya Xue: Supervision, Validation. Yajuan Yu: Software, Investigation, Writing – review & editing, Reviewing and Editing, Validation, Resources, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Acronym

| Acronym   | Description                                      |
|-----------|--------------------------------------------------|
| COVID-19  | Coronavirus Disease reported at the end of 2019  |
| CVs       | Commercial Vehicles                              |
| BEVs      | Battery Electric Vehicles                        |
| GHGs      | Greenhouse gases                                 |
| ICEVs     | Internal Combustion Engine Vehicles              |
| PEVs      | Plug-in Electric Vehicles                        |
| PHEVs     | Plug-in Hybrid Electric Vehicles                 |
| PVs       | Passenger Vehicles                               |
| SDM       | System Dynamics Model                            |

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2022.132291.
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