# Mobility and Energy Policies to Achieve Net Zero Emissions as Key Opportunities to Build a Prosperous Society

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**Abstract**
The transport sector is one of the main sources of global GHG emissions, of which road transport emissions are greatest. The decarbonisation of road transport requires systemic changes combined with technological interventions to optimise the use of transport modes. Given the diverse options for road transport decarbonisation due to differences in technological development and commercialisation levels across geographies, interventions that lead to local development or contribute to addressing societal challenges at each locality are warranted. The decarbonisation of mobility can lead to widespread structural change and should be seen not only as a contribution to addressing the grave problem of the climate crisis, but also as an opportunity to realise a prosperous society with mobility for all.

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## 1. Introduction

In 2019, direct greenhouse gas (GHG) emissions from the transport sector were 8.7 $GtCO_2eq$ (up from 5.0 $GtCO_2eq$ in 1990) and accounted for 23% of global energy-related $CO_2$ emissions. About 70% of direct transport emissions came from road vehicles (passenger and freight in road transport)[1]. Emissions from the transport sector in industrialising countries have been on the rise and are slated to increase further in the coming decades[1]. Working Group III (WG3) of the Intergovernmental Panel on Climate Change (IPCC)'s 6th Assessment Report (AR6) illustrates that emissions are rising from urban areas[2] and land-based passenger and freight transport, especially in rapidly growing Asia and Africa[1]. Models indicate that, without intervention, $CO_2$ emissions from transport could grow in the range of 16% and 50% by 2050 (medium confidence)[1]. To limit global warming to 1.5°C with no or limited overshoot, global transport-related $CO_2$ emissions must be reduced by 59%

by 2050 compared to 2020 levels; however, even if this milestone were to be achieved, it is projected that a net zero world would only be achieved in the latter half of the century (2073-2075)[1]. The world must urgently decarbonise its transport systems, and, to do so, it is necessary to accelerate $CO_2$ emission reductions immediately.

The decarbonisation of the transport sector, with particular attention to land-based transport, is critical for climate mitigation and requires transformative change, global commitments, and local initiatives. The IPCC Special Report on Global Warming of 1.5°C (SR1.5)'s strong message to take immediate actions prompted a wave of stronger global commitments and ambition at events such as President Biden's Leaders Climate Summit and the 26th UN Climate Conference (UNFCCC COP26) in Glasgow, which allowed many countries including Japan to align itself with the global goal to achieve net zero emissions by 2050. However, existing literature shows that there is a lack of clarity on specific policies and guidelines to meet those commitments, and the process to decarbonise the transport system especially in industrialising countries remains unclear[2].

The decarbonisation of the transport sector requires socio-technical system transitions that combine technological innovation and societal change. Non-state actors, including sub-national and cities, the private sector, and citizens and local communities, are slated to play a significant role in climate mitigation[2]. However, the roles and responsibilities of actors depend on the readiness of interventions, and there is no one-size-fits-all strategy. Countries' strategies need the assessment of feasibility in the near term; shift development pathways to accelerate transitions; climate governance; regulatory and economic instruments; and financial flows. International cooperation, to which Japan may contribute, may be critical enablers for achieving ambitious targets in developing countries in the future. It is also important to analyse the close linkages between mitigation actions, adaptation (climate resilience) planning on the transport service sector[2]. The mitigation actions in the transport sector may have synergies with many Sustainable Development Goals (SDGs), but some options can also have trade-offs.

Based on the findings of the IPCC AR6 WG3 report, this article explores the needs of a transition system to support decarbonisation in the land-based road transport sector in Japan. First, the analysis focuses on Japanese policies relevant to the decarbonisation of road transport and how they compare with global pioneering movements in the US, Europe and Asian countries such as China and India. Then, we discuss opportunities for the creation of a new kind of prosperity made possible by a sustainable transport system.

## 2. Global Trends in Climate Mitigation

### 2.1. Climate Mitigation Options

The land transport sector could contribute to climate mitigation through systemic changes combined with technological interventions to reduce the demand on transport services and optimise the use of transport modes[1]. An assessment of demand-side strategies to mitigate climate change notes a potential reduction of 6.5 $GtCO_2eq$ for land-based transport[3]. The greatest potential to avoid emissions is achieved by providing short-distance low-carbon urban infrastructure for car-free mobility that involves shifting to walking and cycling, and by adopting electric mobility, which could collectively save up to 2t $CO_2eq$ per capita per year[3]. Cities can reduce up to 26% of GHG emissions in 2050 compared to business-as-usual if supported by systemic changes[4]. Transport demand can be managed through socio-cultural interventions, as well as infrastructure use and end-use technology

(Figure 1). The cost of some technologies has decreased significantly, leading to accelerated deployment (Figure 2). Compared to developing countries, developed countries may enjoy accelerated deployment of such technologies because of the falling cost of technologies (e.g., renewable energy for supporting electric vehicles (EVs) and battery technologies for EVs); systemic enablers for behavioural/lifestyle change (supported by teleworking, digitalisation, Big Data, supply chain management, dematerialisation, smart and shared mobility, etc.); enabling policies such as supported by strong research and development; economic instruments (e.g., market-based instruments); and a more welcoming ecosystem for new innovations/initiatives.

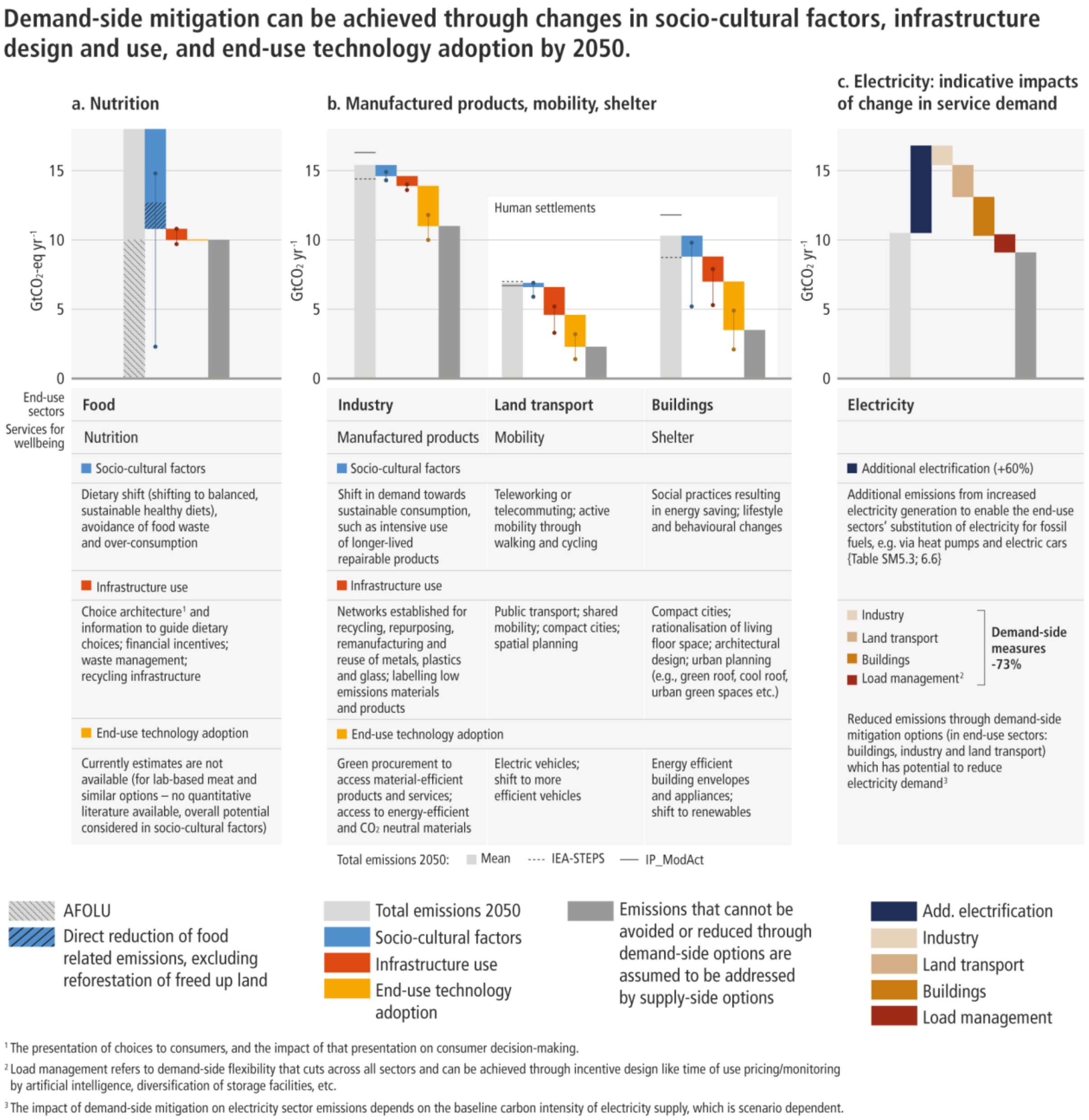


Figure 1. Demand-side mitigation options in the transport sector[3]

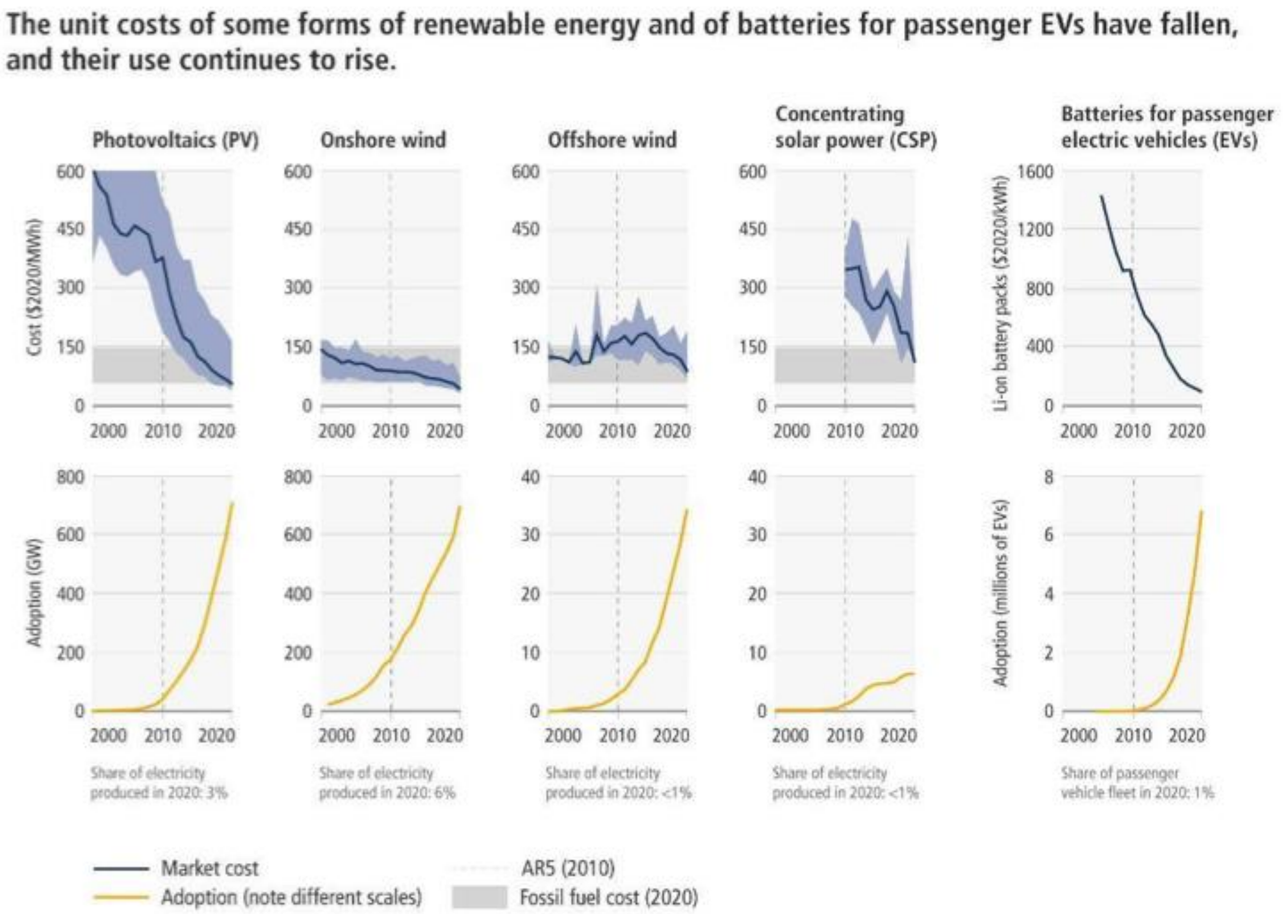


Figure 2. The accelerating adoption of EVs coinciding with the falling costs of EV batteries[2]

However, life cycle assessments (LCAs; assessments that encompass emissions across the life cycle of a product, from production, energy supply, vehicle use and its waste) demonstrate the important role of the upstream energy supply in order to achieve the maximum potential on climate mitigation on road transport. Mid-size light-duty internal combustion engine vehicles (ICEVs), due to their highly efficient manufacturing process, have been shown to have the lowest emission potential on emission intensity initially, but this increases as fossil fuels are used in their operation. In contrast, the emission intensity of battery electric vehicles (BEVs) is slightly higher than ICEVs due to the currently less efficient manufacturing process of the vehicles themselves as well as the batteries; however, emissions over the life cycle can remain low if BEVs are supported by carbon-neutral electricity. This is also true for hydrogen fuel-cell electric vehicles (FCEV). According to the IPCC, bioenergy (biofuels) has potential in the near term because of its availability in some countries. Transitions in the energy supply system are key to maximising the benefit of low-carbon end-use technologies. LCANew approaches such as LCAs, which shift the paradigm from “tank to wheel” to “well to wheel”, will be widely applied in Japan by 2030, Europe by 2024 and China by 2025. Similar approaches could be applied for other transport modes.

## 2.2. Transition Pathways for Mitigation

Decarbonisation efforts in the transport sector, especially technological interventions, are diverse due to differences in technology readiness and commercialisation levels. For climate mitigation strategies that are already in the landscape scale (adopted globally) such as EVs, key stakeholders such as governments (both national and local) and energy suppliers will have to deploy new supporting infrastructure[5]. On the other hand, mitigation options in the regime scale (not mainstreamed yet) such as FCEVs and the shared economy (Mobility as a Service (MaaS) on the demand side[3]) in Japanese localities, need support on the regulatory and economic incentives to speed up the transition process from pilot projects to widespread implementation. Moreover, regarding demand side management, individual motivation and capacity for change differ depending on demographics and geographic context[3]. Individual behavioural change is insufficient for climate change mitigation unless embedded in structural and cultural change[6].

Cultural change, in combination with new adapted infrastructures and policies, is necessary to enable and realise many “avoid” and “shift” options in mobility. A notable example of this is new workstyles that have influenced mobility patterns such as teleworking, which were hardly implemented before the novel coronavirus disease (COVID-19) pandemic. This exogenous shock propelled countries to quickly and widely promote such approaches, demonstrating that radical and sweeping change is possible[3]. In light of their advantages, these approaches are likely to continue to some extent, even in the post-COVID era. Going forward, it is important to promote systemic redesigns that may ultimately drive lifestyle shifts for the better.

## 2.3. Strategies and Policies in Japan and Around the World

The policies and strategies that enable mitigation in the road transport sector differ depending on countries’ commitments, targets, and strengths[2]. The diverse policies and strategies across the world show that transformative pathways to decarbonise road transport may vary. Some countries have more ambitious actions related to the development of EVs, demand side management and urban designs. Strategies include country-level roadmaps, setting targets for the penetration rate/perturbation of end-use technology such as EVs or FCEVs in 2030 and 2050. Economic instruments include fiscal support, incentives and subsidies for industry, reductions in import tariffs, promotion of local manufacturing, incentives and subsidies for end users, and tax breaks for EVs (Table 1). There are also targets for supporting infrastructures such as charging systems, including the distribution of facilities and new business models. In the last decade, the decarbonisation of end-use technology interventions such as BEVs has grown rapidly, particularly in China, the US, and Europe. While subsidies were shown to be the most important and effective measure to promote EVs, some countries have since announced their abrogation[7].

The charging density, fuel price and priority on the road are also positively correlated with the country's EVs share[7]. China has implemented several transformative actions to change institutional arrangements, such as interim measures for the administration of lithium-ion batteries[8] and financial support for purchasing EVs from the central and provincial governments[9]. Meanwhile, China has also implemented regulatory and economic instruments such as controlling vehicle ownership in big cities such as Shanghai and Beijing, as a continuation of incremental actions by local governments. Meanwhile, India's transition to electric mobility is guided by energy security, air pollution amelioration and GHG emission reductions from the transport sector[10]. India focuses on "easy-to-electrify" domestic vehicle markets such as e-motorbikes (2-wheelers) and e-trikes (3-wheelers). The new manufacturing activities and increase in electricity consumption are expected to generate many jobs in 2030[6].

Table 1 Action Plans, Targets and Enabling Environments on EV and FCEV in the EU, US, China, India and Japan

| Country | ***Action Plans and Targets*** | ***Enablers*** |
|---|---|---|
| EU | No new sales of ICEV in 2035, 100% of emissions from cars and vans to be zero by 2035[11] | Some countries provide direct subsidies for purchasing EVs, while others subsidise indirectly through tax exemption. EVs are allowed to use high occupancy vehicle (HOV) lanes in several countries[7]. |
| USA | There is no specific target on removing ICEV, although some state governments are signatories of the COP26 declaration on accelerating the transition to 100% zero emission cars and vans[12].<br><br>Zero-emission vehicle sales (new; including BEV, PHEV, FCEV): 50% in 2030[13] | In the US, a federal tax credit of US$ 2500 to US$ 7500 is available for each new EV purchased based on vehicle size and battery capacity. Some states provide tax credits, whereas others exempt EVs from state sales and use taxes[9].<br><br>EVs are allowed to use HOV lanes in several states and parking is free for EVs in several cities[9]. |
| China | Automobile Industry Mid-and Long-term Development Plan (2017)[9]<br>Phaseout of ICEVs by 2035[14]<br>BEV, PHEV, FCV sales: 20% (by 2025) and 50% (by 2030)[9]<br>A million FCV in 2030[15]<br>Hybrids share to be 75% of all gas-powered cars by 2030, and 100% by 2035[14] | Financial support for the promotion of new energy vehicles in 2016-2020[8,16]<br>Both central and provincial governments provide subsidies to purchase EVs[9]<br>Guide for development of EV charging infrastructure (2015-2020)[8] |
| India | National Electric Mobility Mission Plan (NEMMP) 2020[10]<br>EVs and FCV sales: 15% of 2-wheelers, 30% of light-duty vehicles (LDVs) by 2023[15]<br>At least 65% of all new sales to be electric by 2030[17]<br>Phase-out ICEV by 2040 (COP26 declaration on accelerating the transition to 100% zero emission cars and vans)[12] | Plan to add 500 GW of new renewable power to the electricity grid by 2030[16]<br>Key national policy for EVs: Faster Adoption and Manufacturing of Electric Vehicles (FAME II) scheme[18]<br>Phased Manufacturing Plan[19] |

| | | |
|---|---|---|
| Japan | Roadmap for EVs and PHEVs toward the dissemination of Electric Vehicles and Plug-in Hybrid Vehicles (2016)[9]<br>Ban of new sales of ICEVs in 2035[20]<br>All new personal vehicles are electric (including hybrid, etc.) by 2035[20]<br>Mid-term: FCV stock to 200,000 (2025) and 800,000 (2030)<br>Long-term: 100% sales (BEV, PHEV or HEV)[15] | Tax breaks for EVs[9]<br>Green vehicle purchasing promotion measures: up to US$ 7000 for purchasing BEVs[21]<br><br>Local governments also have programmes to subsidise the purchase of green vehicles (i.e. Tokyo[22]). |

## 3. Climate Mitigation Actions on Road Transport in Japan

### 3.1. National Policies and Strategies

Due to demographic challenges such as ageing, population decline, and migration, building and maintaining a sustainable transport system in Japan is becoming increasingly difficult, especially when it comes to public transport infrastructure. For example, as of 2018, 69% of local bus lines with at least 30 buses in their fleet reported being in the red[23]. The viability of public transport as a business is called into question in especially rural areas, which report having over 70% of train lines with negative profit[23]. In terms of employment, there has been a 25% decrease in the number of bus drivers in rural areas since 2000; meanwhile, in the three largest metropolitan areas in Japan, the proportion of bus drivers compared to 2000 decreased temporarily in the last 20 years, but has since largely recovered[23].

The Government of Japan has set forth several targets for the transport system in 2025, including a push to increase Light Rail Transport (LRT) introduction from 34% (fiscal 2021) to 42% by fiscal 2025[20]. Some Japanese cities are moving ahead to tackle both the issue of carbon emissions and depopulation and/or urban sprawl by using the electrification of the transport system to create compact cities. For instance, Toyama City in Toyama Prefecture overcame urban sprawl caused by motorisation and the merging of municipalities in the area through the development of a public transport system centred around the Toyama Portram and Centram lines (Figure 3). This new public transport system improved the walkability of the city, reduced travel time, promoted migration within the city (as opposed to out-migration and thus further depopulation), and increased the value of land in the city centre[24]. GHG emissions also declined. Utsunomiya City in Tochigi Prefecture similarly plans to develop an LRT system along with on-demand small buses and taxis to meet the transport demands of its shrinking population and aim towards a compact city[25].

Figure 3. A Toyama Light Rail train running past the Toyama Castle, a symbol of the city (Photo credit: Toyama City)

At the same time, the government is also interested in promoting artificial intelligence (AI) and self-driving vehicles. Cities such as Shiojiri City (Nagano Prefecture) are piloting self-driving electric buses, which uses both zero-emission vehicles and AI technology to cope with the lack of bus drivers[25].

Meanwhile, the government is also promoting active mobility through its Bicycle Use Promotion Plan, aiming to expand bike lanes, with a length of 2,930 km in total as of the end of fiscal 2019, to make bicycle transport safer and more enjoyable[5,26]. To do so, the government aims to increase the number of local governments with plans to promote cycling networks from 89 (fiscal 2021) to 400 by fiscal 2025[20].

Regarding electric vehicle deployment, despite the country's goal of achieving 100% EVs by 2035, progress has been slow. In the first quarter of 2021, there were roughly 11,000 EVs sold in Japan, a 20% increase from the year before, which is stagnant compared to the 150% increase in sales seen in the EU[5]. In one survey of 550 car owners familiar with the SDGs, it was found that only 4.5% currently own BEVs[27]. However, when considering replacing their current vehicle, roughly 40% stated they would consider BEVs, while around 55% and 32% would consider HEVs and PHEVs, respectively[27]. In terms of barriers, a 2022 Deloitte survey illustrated that consumers are concerned about the lack of charging infrastructure, the inability to charge at home, the cost of the vehicle, and distance traveled on a single charge, among others (Figure 4)[28].

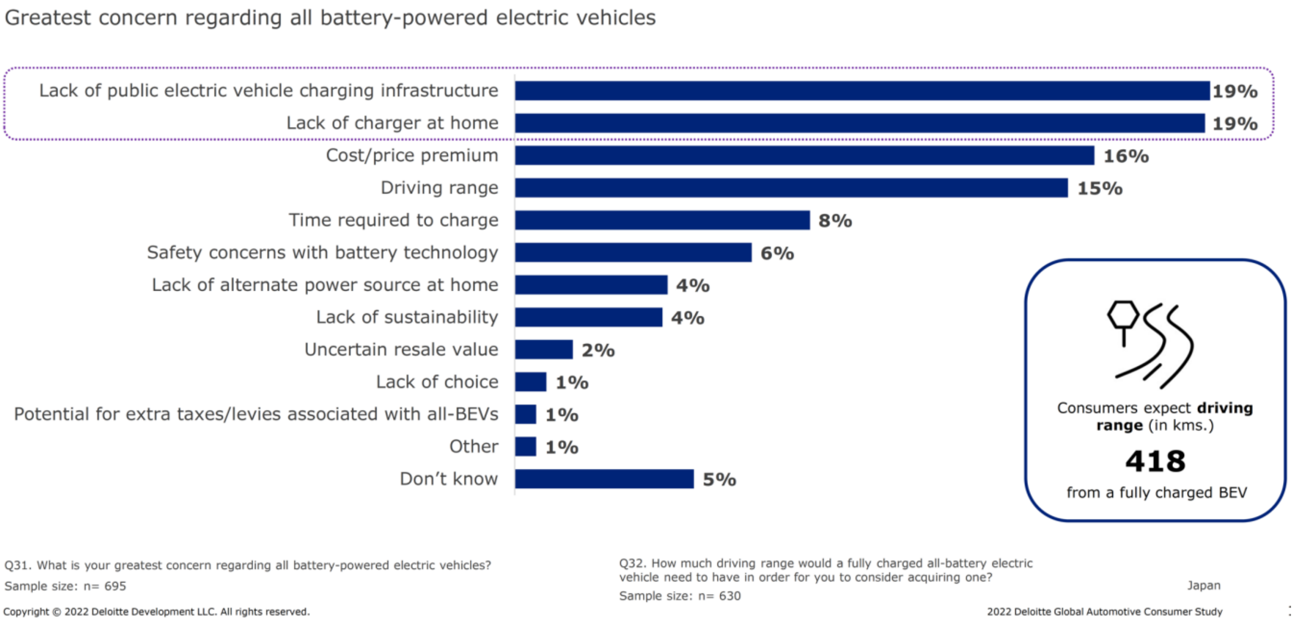


Figure 4. Major concerns among Japanese respondents regarding BEVs in 2022 (translated by the Deloitte Tohmatsu Group based on the Japanese figure[28])

Notably, to achieve the decarbonisation of transport, the deployment of renewable energy is key. Japan aims to increase the share of renewables in the energy mix to 36-38% by 2030, but as of 2020, renewables make up 20.8% of the electricity generated in the country[29,30]. Fossil fuels remain dominant in the energy system despite slowly decreasing in share, accounting for 74.9% in 2020[30]. Meanwhile, decentralised renewable energy in Japanese local areas may be key to fostering disaster-resilient and sustainable local communities in the long run. However, there are financial and technological hurdles in the way of implementation, including "mobilising finance", "setting up an implementation mechanism on the supply side", and "securing demand"[23].

### 3.2. Demand Side Management

Since the onset of the COVID-19 pandemic, mobility patterns have shifted dramatically. Importantly, public perception around what constitutes "necessary travel" has changed[31,32], with white-collar office work being replaced by remote work, and education (especially higher education) replaced by e-learning. This implies that, due to a reduction in mobility in general, the impacts of the increased use of personal automobiles temporarily in lieu of public transport are not as pronounced[31].

In the post-pandemic society, people may weigh the risks and benefits of virtual and physical spaces, people in the post-pandemic society may optimise their use based on the circumstance, and may only opt for physical spaces (which require transport to and from the venue) when virtual substitutes are clearly not viable[32]. As technologies such as virtual reality (VR) become developed, the justification to use physical spaces is likely to become even more stringent, which will have implications for the demand for mobility[32].

Such demand side management, however, is highly contextual and may differ considerably between localities in Japan. When various lifestyle options were investigated for their $CO_2$ reduction potential, the effect of fully adopting specific mobility-associated behaviours such as ridesharing and teleworking was greater in mid-sized cities than in large metropolitan areas[33]. Still, for mobility, public transport, sharing and electrification of vehicles, and reducing distance traveled in general (through micro-tourism, compact cities, etc.) are all effective policy and technological options to be localised to improve the quality of life while reducing emissions[33].

When considering policy options, it is critical to consider the concerns of marginalised or potentially vulnerable groups, such as senior citizens, people living with disabilities, and other people with limited mobility. In addition to deploying efficient and decarbonised mobility technologies, new services and approaches, such as those promoting Mobility as a Service (MaaS), are necessary to foster a society where the right to mobility is truly universal[32]. According to a survey conducted in Aichi Prefecture, senior citizens traveled less in 2020 than they had before the pandemic, and, by the end of 2020, the number of times they drove, took public transport (buses, trains) or taxis decreased, while the number of times they rode private transport driven by another person increased compared to before the pandemic[34]. This implies that initiatives to promote ridesharing and passenger-freight mobility sharing are key, with a view to consider planning compact cities in the longer term.

### 3.3. Review of the Progress and Challenges on End-Use Technology Deployment

Technologies for decarbonising land-based transport are at different developmental and implementation stages in Japan. By 2030, the government expects progress in cost reduction and hence the much wider dissemination of EVs and battery technologies, which have already been developed, piloted, and become adopted[35]. Institutional frameworks and standards for batteries across the life cycle, including visibility of life cycle emissions, labeling for household batteries, and the introduction of financial instruments will be further promoted[35]. Meanwhile, the government plans to continue to support the research and development of affordable and efficient synthetic fuels and next-generation batteries[35].

For the deployment of hydrogen-fueled vehicles, the cost competitiveness of FCVs compared to ICEVs and EVs is a major barrier[36]. Another significant barrier is thought to be the cost of green hydrogen production; simulations have suggested that costs for hydrogen production are lowest through fossil fuels[36]. Thus, more research and development to bring the cost of green hydrogen down will be needed to align FCVs with net zero goals.

In addition to such technological and social system innovations, the government plans to pilot programmes that will transform the way personal vehicles are used, promoting MaaS, and digitising urban infrastructure for technologies such as self-driving vehicles[35]. On the freight transport side, self-driving vehicles and delivery robots are already being piloted in some contexts, but legislation and incentives to further expand these efforts are needed, including overcoming data collection challenges in Japan for pilots done on public roads[5,32].

### 3.4. Sustainable Development Pathways in the Japanese Context

Decarbonisation should be seen not only as a solution to a grave problem, but also an opportunity to create a new kind of wealth for society. It should aim to create a sustainable transport system that tackles demographic (ageing, depopulation) and economic (regional development) challenges in Japan. Sustainable transport transitions contribute to the ultimate goal of realising a prosperous net zero society.

In some local contexts, delivery companies and bus or train companies have implemented passenger-freight mobility sharing programs (i.e., in which cargo is loaded to fill the remaining space on passenger buses and trains) to meet the demand for mobility and freight transport. For example, to meet the transport demand in two neighboring localities, the Higashimera District of Saito City and Nishimera Town in Miyazaki Prefecture, the logistics company Yamato Transport has begun delivering parcels through, in part, operating freight-passenger buses along the local bus line[37]. This has also improved Yamato Transport's service: by creating an arrangement where workers no longer return to the holding centre in Saito City and spend more time in the local community, the company was able to delay the final pickup time for same-day delivery to 17:00[37]. More recently, due to the impacts of COVID-19 on revenues for public transport, similar approaches are being tested or implemented to transport cargo across the archipelago via bullet train[38] and express buses to deliver fresh produce to Tokyo supermarkets[39].

Moreover, opportunities to overcome the challenges to the financial and economic sustainability of the country's transport system are tied to promoting inclusive policies to provide new services to foreign nationals and those with disabilities, and supporting new workstyles such as teleworking, which allow urban dwellers to move to rural areas. There has been some renewed interest in out-migration to rural areas since the beginning of the COVID-19 pandemic; however, policy incentives are necessary to ensure an enabling environment for such new workstyles[23].

Finally, it goes without saying that decarbonised transport is made possible by the decarbonisation of the energy system. In addition to the expansion of renewable electricity for EVs and the production of hydrogen through decarbonised means to fuel FCVs, further research on green hydrogen production and efficient FCV manufacturing is key to scale up their use. On the other hand, innovations such as BEVs can play a critical role in stabilising an energy system based on renewables. Notably, the batteries in BEVs can help balance energy demand and supply by storing electricity from intermittent sources such as solar power, leading to greater energy security[5]. Early evidence suggests that a high EV battery capacity (in cities) can reduce the cost of the energy transition toward net zero emissions[40]. Meanwhile, for the decentralisation of the country's energy system, EVs can play an integral role to replace the role of an electricity grid by delivering power to surrounding households[41]. Leveraging the strengths of EVs and related innovations can create a decarbonising virtuous cycle between transport and energy systems, propelling the country toward its 2050 vision.

## 4. Conclusions

Global scientific reports developed by the world's leading scientists, such as the IPCC SR1.5 and the IPCC AR6, concur that immediate action to limit global warming to 1.5°C is imperative. Science-based decision-making needs to be strengthened in Japan. Research focusing on policy analysis and climate governance needs to be improved to assess feasibility, provide more options on shifting development pathways, and speed up the response and transition process. LCAs need to be applied in all types of end-use technology interventions. Such studies would contribute to the global literature on decarbonising land-based transport, and, through strengthening the science-policy interface, contribute to the achievement of a prosperous net zero Japan.

For road transport to contribute to Japan's goal to become net zero by 2050, a new socio-technical system must be built through both technological and social innovations. Through leveraging synergies between decarbonisation and SDGs, there is an opportunity to foster resilient transport systems. Japan faces issues such as rural depopulation and decay, and natural disasters, so the new transport system must be designed in a way that addresses such issues. Going forward, experiences from the COVID-19 pandemic demonstrate that there are unseen opportunities such as teleworking and societal-level policies to decarbonise road transport, which should be discussed and pursued further.

## Notes

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## Bibliography

1. Jaramillo, P. et al. Transport. in Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (eds. Shukla, P. R. et al.) (Cambridge University Press, 2022).
2. Summary for Policymakers. in Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (eds. Shukla, P. R. et al.) (2022).
3. Creutzig, F. et al. Demand, services and social aspects of mitigation. in Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (eds. Shukla, P. R. et al.) (Cambridge University Press, 2022).
4. Lwasa, S. et al. Urban systems and other settlements. in Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (eds. Shukla, P. R. et al.) (Cambridge University Press, 2022).
5. Cabinet Secretariat et al. Green Growth Strategy Through Achieving Carbon Neutrality in 2050. (2021).
6. Akenji, L., Lettenmeier, M., Koide, R., Toivio, V. & Amellina, A. 1.5-Degree Lifestyles: Targets and Options for Reducing Lifestyle Carbon Footprints. https://www.iges.or.jp/en/pub/15-degrees-lifestyles-2019/en (2019).

7. Wang, N., Tang, L. & Pan, H. A global comparison and assessment of incentive policy on electric vehicle promotion. Sustain. Cities Soc. **44**, 597–603 (2019).
8. Liu, D. & Xiao, B. Exploring the development of electric vehicles under policy incentives: A scenario-based system dynamics model. Energy Policy **120**, 8–23 (2018).
9. Asia Pacific Energy Research Centre (APERC). Challenges and Perspectives of Deployment of BEVs and FCEVs. Inst. Energy Econ. Jpn. (2020).
10. Soman, A., Kaur, H., Jain, H. & Ganesan, K. India's electric vehicle transition: can electric mobility support India's Sustainable Economic Recovery Post Covid-19? https://www.ceew.in/sites/default/files/CEEW-India's-EV-Transition-Post-COVID-19-22Dec20.pdf (2020).
11. European Council. The EU's plan for a green transition. European Council https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/ (2022).
12. COP26 Presidency. COP26 declaration on accelerating the transition to 100% zero emission cars and vans. (2022).
13. Government of the United States of America. FACT SHEET: President Biden Announces Steps to Drive American Leadership Forward on Clean Cars and Trucks. WH.gov https://www.whitehouse.gov/briefing-room/statements-releases/2021/08/05/fact-sheet-president-biden-announces-steps-to-drive-american-leadership-forward-on-clean-cars-and-trucks/ (2021).
14. Tabeta, S. China plans to phase out conventional gas-burning cars by 2035. Nikkei Asia (2020).
15. He, X. et al. Asia Pacific road transportation emissions, 1900–2050. Faraday Discuss. **226**, 53–73 (2021).
16. Oxford Analytica. South Asia's electric mobility goals are overambitious. https://www.emerald.com/insight/content/doi/10.1108/OXAN-DB244770/full/html (2019).
17. Shah, A. Indian businesses seek government support to meet 2030 EV target. Reuters (2021).
18. IEA. Policies to promote electric vehicle deployment. https://www.iea.org/reports/global-ev-outlook-2021 (2021).
19. Asghar, R. et al. Electric vehicles and key adaptation challenges and prospects in Pakistan: A comprehensive review. J. Clean. Prod. **278**, 123375 (2021).
20. 国土交通省 [Ministry of Land, Infrastructure, Transport and Tourism]. 交通政策基本計画 [Basic Transport Policy]. (2021).
21. Hirosawa, M. Japan to double EV subsidies to match U.S. and Europe. Nikkei Asia (2021).
22. Bureau of Environment, Tokyo Metropolitan Government. Tokyo ZEV Promotion Strategy. (2019).
23. 国土交通省 [Ministry of Land, Infrastructure, Transport and Tourism]. 国土の長期展望専門委員会最終とりまとめ参考資料 [National Long-Term Prospects Committee Meeting Summary Materials]. (2021).
24. Kriss, P., Miki-Imoto, H., Nishimaki, H. & Riku, T. Toyama City: Compact City Development. http://hdl.handle.net/10986/34816 (2021).
25. Biz Frontier. クリーン交通 都市に活力 進む産官連携、観光に順風. 日本経済新聞 [Nikkei] (2022).
26. 国土交通省 [Ministry of Land, Infrastructure, Transport and Tourism]. 自転車活用推進計画 [Bicycle Use Promotion Plan]. (2021).

27. 株式会社 KINTO [KINTO Corporation]. 2021 年、電気自動車(BEV)保有率は 4.5% 一方、次回の買い替えは 37.8%が BEV を検討 [BEV ownership in 2021 is at 4.5%, but 37.8% consider BEV for their next car]. (2021).
28. デロイト トーマツ グループ [Deloitte Tohmatsu Group]. 2022 年度版「グローバル自動車消費者調査（日本市場編）」 [FY2022 Global Automotive Consumer Study (Japanese Market Version)]. (2022).
29. 経済産業省資源エネルギー庁 [Agency for Natural Resources and Energy, METI]. 第 6 次エネルギー基本計画 [6th Strategic Energy Plan]. (2021).
30. ISEP. Share of Electricity Generated from Renewable Energy in 2020 (Preliminary Report). Institute for Sustainable Energy Policies https://www.isep.or.jp/en/1075/ (2021).
31. Aoki, H. ポストコロナのモビリティ社会 [A New Mobility Society After COVID-19]. IATSS Rev. **46**, 57–63 (2021).
32. Kanoshima, H. アフターコロナの移動の形とモビリティのあり方 [Future Prospects for Mobility and Transportation After the COVID-19 Pandemic]. IATSS Rev. **46**, 172–179 (2022).
33. Koide, R. et al. Exploring carbon footprint reduction pathways through urban lifestyle changes: a practical approach applied to Japanese cities. Environ. Res. Lett. **16**, 084001 (2021).
34. Yamauchi, S. et al. COVID-19 流行に伴う高齢者の行動と利用移動手段の変化 [Change of Behavior and Mobility in Elderly during COVID-19 Epidemic]. 自動車技術会論文集 **52**, 1143–1148 (2021).
35. 国土交通省 [Ministry of Land, Infrastructure, Transport and Tourism]. グリーン社会の実現に向けた国土交通分野における環境関連施策・プロジェクトについて（主要取組概要）[Environmental measures and Projects in the Land and Transport Sectors Toward Achieving a Green Society (Summary of Main Measures)]. (2021).
36. Otsuki, T., Komiyama, R. & Fujii, Y. Techno-economic Assessment of Hydrogen Energy in the Electricity and Transport Sectors Using a Spatially-disaggregated Global Energy System Model. J. Jpn. Inst. Energy **98**, 62–72 (2019).
37. ヤマトホールディングス [Yamato Holdings Co., Ltd.]. 「客貨混載（きゃくかこんさい）」で、地域のお困りごと解消と宅急便サービスの向上を両立 [Balance of Addressing Regional Concerns and Improving Delivery Services through Passenger-Freight Transport]. ヤマトホールディングス [Yamato Holdings] https://www.yamato-hd.co.jp/csr/higlights/2017highlights01.html (2017).
38. The Japan Times. JR firms starting to use shinkansen for freight. The Japan Times (2021).
39. 東京新聞 (The Tokyo Shimbun). 都内スーパーへ 片品の新鮮野菜を高速バスで直送 関越交通など「客貨混載」試行 [To Tokyo's Supermarkets: Katashina's fresh produce to be delivered by express bus through a trial of passenger-freight transport by Kanetsu Corporation]. 東京新聞 (The Tokyo Shimbun) (2021).
40. Kawasaki, N. & Muromachi, Y. Building Zero-Emission Cities with EV, PV, and Stationary Storage Battery System in Tokyo Metropolitan Area. J. City Plan. Inst. Jpn. **56**, 1366–1373 (2021).
41. Ichii, K., Mitarai, A. & Taniguchi, M. Transporting power to "satellite smart towns": Electric vehicle augmentation and replacement of electric grid transmission. J.

City Plan. Inst. Jpn. **55**, 569–576 (2020).