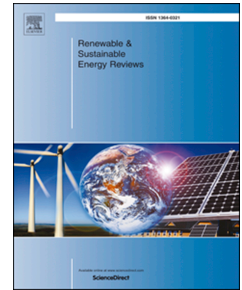


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Policy mixes to achieve sustainable mobility after the COVID-19 crisis

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Journal Pre-proof

Policy mixes to achieve sustainable mobility after the COVID-19 crisisGriffiths, S.^{1,*}Furszyfer Del Rio, D.^{2,3}Sovacool, B.²* corresponding author, steven.griffiths@ku.ac.ae

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Abstract:

The COVID-19 pandemic has the potential to have lasting impacts on energy and the environment at the global scale. Shelter-in-place measures implemented to mitigate the spread of COVID-19 have resulted in expectations for 2020 global energy demand to contract by nearly 5% with related global CO₂ emissions declining by as much as 7%. Exactly how long and to what extent we will see continue to see energy demand, CO₂ and related greenhouse gas (GHG) emission destruction resulting from COVID-19 is uncertain but dependent on global policy responses to the pandemic. Policy responses targeting the transportation sector, particularly ground-based transportation, can stimulate a sustainable mobility transition that mitigates the potential for long-term environmental damage.

This paper reviews and examines social and cultural dynamics of transportation and extends state-of-the-art knowledge to consider how events surrounding the Covid-19 crisis may have created a sustainable mobility opportunity though (1) avoiding unnecessary transportation

volume, (2) shifting transportation norms and practices and/or (3) improving the carbon-efficiency of transportation systems. Relevant policies for a low-carbon transportation transition are considered and those most appropriate to the current context proposed with consideration of key factors that may help or hinder their implementation success.

Highlights:

- Shows how Covid-19 creates an opportunity for sustainable mobility
- Defines three narratives to assess the sustainable mobility opportunity
- Describes avoid, shift and improve policies for sustainable mobility
- Shows that policy mixes need to prioritize cities and consider local context
- Suggests policies must promote and protect zero carbon and public mobility

Keywords: Covid-19; sociotechnical transitions; sustainable mobility; policy; cities

Word Count: 5,600

List of Abbreviations:

- Covid-19 = Novel Coronavirus
- CO₂ = carbon dioxide
- EV = electric vehicle
- GDP = gross domestic product
- GHG = greenhouse gas
- ICE = internal combustion engine
- ICT = information and communication technologies
- NO₂ = nitrogen dioxide
- SDG = sustainable development goals
- UN = United Nations
- ZEV = zero emission vehicle

1 Introduction

COVID-19, a global health pandemic that has had far reaching societal impacts, is expected to have long-term impacts on energy and the environment at the global scale, although the extent and specific trajectory of these impacts are uncertain [1]. By the end of April 2020, shelter-in-place measures implemented to mitigate the spread of COVID-19 had resulted in complete or partial lockdowns for nearly 4.2 billion people (or 54% of the global population), which, according to the International Energy Agency (IEA), represented approximately 60% of global GDP [2]. Consequently, the share of global primary energy demand subject to full or partial lockdown went from 5% in mid-March 2020 to 52% by the end of April 2020 [3] and this has put the globally economy on track to shrink by an estimated 4.4% in 2020 [4]. The IEA has further forecast that global primary energy demand for all of 2020 will contract by roughly 5% and related global CO₂ emissions will decline by roughly 7% [1].

Exactly how long and to what extent we will see energy demand, CO₂ and related greenhouse gas (GHG) emission destruction resulting from COVID-19 is being closely observed and debated. There inevitably will be a global economic recovery from the economic shock of global shelter-in-place measures and this recovery could be rapid or drawn out [1, 5]. The extent to which a reduction in GHG emissions continues during this recovery, and hence the extent to which the economic recovery is consistent with long-term climate goals of the 2015 Paris Agreement [6], will depend on how global policy responses are structured [7]. In April 2020, all G20 nations (including the majority of EU member states), which represent nearly 85% of global GDP and 80% of global carbon emissions [8], had signed into law fiscal policy measures totaling over US\$7.3 trillion [9] and this number rose to about US\$9 trillion at the global level [3]. By October 2020, G20 countries had committed US\$12.7 trillion toward stimulus for COVID-19

economic recovery although only US\$3.7 trillion was directed to sectors that significantly impact carbon emissions and the environment [10].

While national policy measures in the early stages of the pandemic were oriented toward rescue of healthcare systems and workforces rather than recovery, stimulus packages are now being defined and implemented with long-term climate impacts that will be realized over the course of the coming decades. Climate Action Tracker has suggested that low-carbon energy sector investments on the order of ~1.5 to 2.3% GDP annually, coupled with decreased fossil fuel investment and additional climate policy measures, could possibly stimulate short-run economic activity while simultaneously achieving the Paris Agreement climate ambitions [11]. The IEA has shown that spending USD\$1 trillion per year, or approximately 0.7% of current global GDP, between 2020 and 2024 on an integrated sustainable recovery plan would have similar impact [3]. In a similar fashion, the International Renewable Energy Agency (IRENA) has suggested spending USD\$2 trillion per year between 2021 and 2023 on clean energy and related infrastructure is need to address the global climate agenda [12]. The question for policymakers is how such low-carbon investments can be targeted to result in long-term global benefits despite the short-term tragedies and challenges that have resulted from COVID-19. The magnitude of this challenge is apparent from that fact that as of October 2020, stimulus spending plans proposed by G20 economies are expected to have a net-negative environmental impacts with exceptions only found in the EU, France, Spain, the United Kingdom (UK) and Germany [8, 10].

This paper extends and deepens the nascent literature on mobility as part of a broader sociotechnical system is being transformed as a result of COVID-19 [13, 14]. More specifically, it provides a review and assessment of COVID-19's shock to the global transportation landscape

and the opportunity for this shock to catalyze a sustainable transformation of ground passenger transportation. The social and cultural dynamics of transportation are reviewed, extending current state-of-the-art knowledge [15, 16] to consider how events surrounding the COVID-19 crisis may have created an opportunity to (1) avoid unnecessary transportation volume, (2) shift transportation norms and practices and/or (3) improve the carbon-efficiency of transportation systems. Relevant policies for a low-carbon transportation transition are assessed and those most appropriate to the current context are proposed with consideration of key factors that may help or hinder their implementation success.

Given the recency of the COVID-19 pandemic, a narrative review methodology, described in detail by Sovacool et al. [17], is employed to synthesize insights from the literature pertaining to sociotechnical transitions, the emerging literature related to the impacts of COVID-19 on mobility and a broad range of reports on the energy, climate and economic impacts of COVID-19. The narrative review approach is particularly fitting to this work as it focuses on exploratory review to synthesize multi-disciplinary insights and/or cover topics where insufficient literature exists to conduct a systematic review or meta-analysis [17].

2 Sustainable mobility: an opportunity arising from crisis

In this paper we define sustainable mobility, a well-established concept in the literature [18-20], as achieving an overall volume of physical mobility, modal splits and transport technologies that efficiently meet basic mobility needs while supporting ecosystem integrity and limiting GHG emissions to a level that is consistent with international efforts toward sustainable development. Given this definition, the transportation sector, particularly light-duty vehicles for ground passenger transportation, should be a primary focus of low-carbon stimulus investments and policies. Cars, which are part of an intricate mobility sociotechnical system [21, 22], account

for approximately 7% of global GHG emissions and for more than 50% of total transportation emissions [23].

Further, the global stock of passenger vehicles is projected to grow by one-third by 2040, despite a major downturn in auto sales in 2020 due to the COVID-19 pandemic [24]. This indicates that interventions are required now to avoid lock-in of future transportation emissions that are at far greater levels than today. Economically, global car sales in 2020 will fall by about 15% relative to 2019 while the use of public transport in cities has fallen by 50-90%, costing cities billions in lost revenues [3, 25]. With the automotive sector directly and indirectly employing around 15 million workers globally and public transportation employing approximately 13 million more [3], economic recovery of the transportation sector is perhaps equally important to climate considerations.

Although the ground transport sector had the greatest contribution (43%) to a truly massive peak reduction in daily global CO₂ emissions of 17%, which was achieved on April 7, 2020 during the COVID-19 lockdowns [26], the degree to which even a fraction of such curtailed emissions will last is unclear. This is because the transport sector has embedded consumption habits that are difficult to change [27]. Sociotechnical systems, such as transportation, evolve over the course of decades with a mix of technology, policy, economics and culture that lead to path dependence and resistance to change. Incumbent systems are defended and incrementally improved by entities whose actions are guided by sociotechnical regimes that tend to resist change [28, 29]. As detailed by Mattioli et al., the perpetuation of our current car-dependent transport regime results from a complex sociotechnical system that interlinks the automotive industry, the provision of car infrastructure, the political economy of urban sprawl, the provision of public transport and cultures of car consumption [30].

Nonetheless, major landscape developments, such as COVID-19, can pressure an existing regime such that a window of opportunity is created for change and niche innovations emerge into the mainstream [31]. There are already numerous examples of how COVID-19 is changing social behavior and transportation patterns [13, 32-34]. Working and shopping from home have become prevalent along with avoiding public transportation in favor of personal car use and active (or soft) modes of transportation, particularly cycling and walking [3, 32, 35, 36]. Citymapper¹, for instance, has shown that road use disappeared in some of the busiest cities of the world during lockdowns and did not resume to pre-pandemic levels even as lockdowns eased in many locations in Summer 2020 (Figure 1) [32, 37].

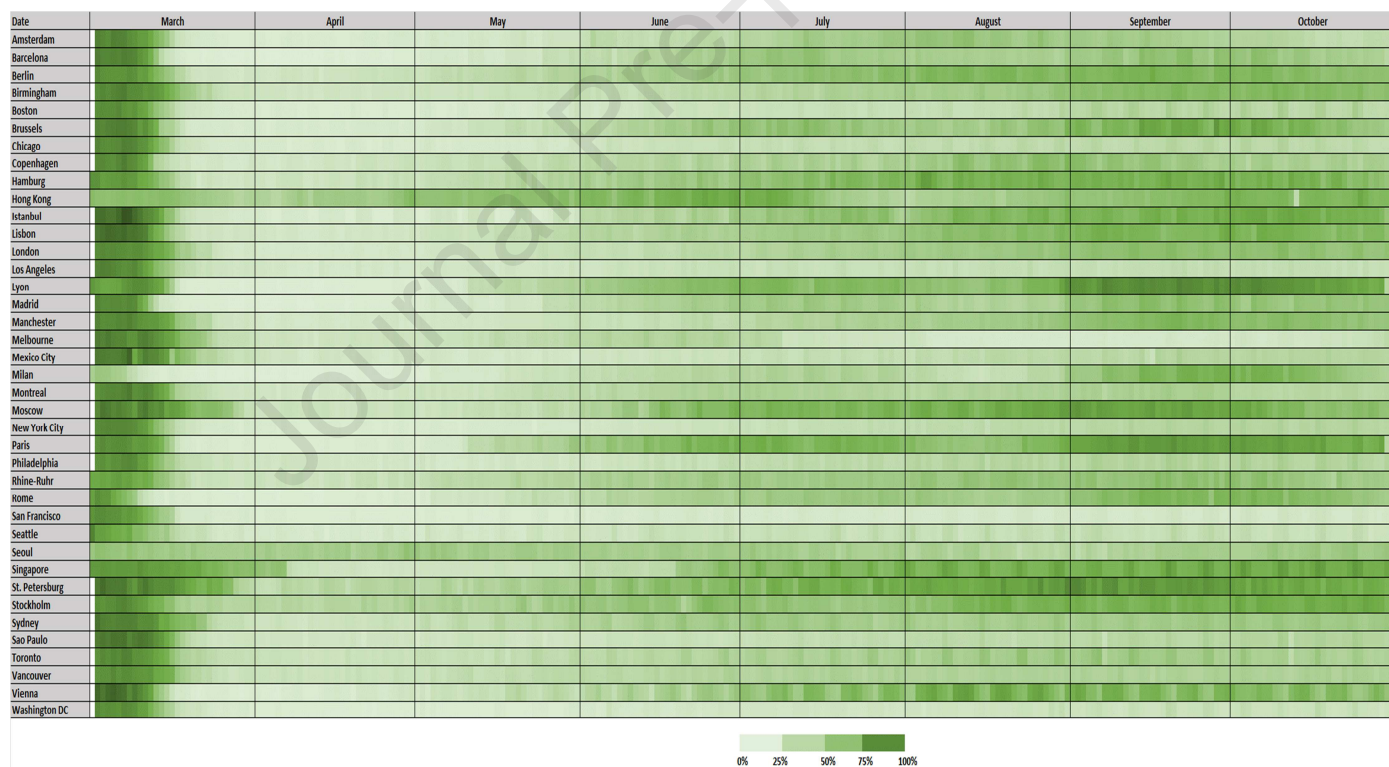


Figure 1: Citymapper Mobility Index showing planned trips using the Citymapper app in selected cities between March and October 2020 relative to normal planning activity, defined as the 4 weeks between Jan 6th and Feb 2nd, 2020. Dark green represents 100% of normal activity while white represents 0%. (Source: Authors with data from [32]).

¹ Citymapper is a public transit app as well as a mapping service that displays real time transport options, between any two locations in a supported city. Citymapper data is provided for download and analysis at <https://citymapper.com/cmi>.

Tollefson reports that Europe and USA had their largest declines in carbon emissions from their transportation sectors while China, the first country to both enter and exit lockdowns, also had a significant reduction in carbon emissions from transportation although this was relatively short-lived as emissions bounced back quickly as travel restrictions were lifted [38]. Meanwhile cycling activity in China, Germany, Ireland, the United Kingdom, the United States and elsewhere surged as a result of social distancing measures, with some locations seeing increases of more than 150% in cycling activity following the COVID-19 outbreak [39]. “Pop-up” bike lanes and other short-term measures taken to support active transportation have the potential to be turned into permanent infrastructure that contributes to long-term sustainable mobility in towns and cities around the world [36]. The Global Mayors COVID-19 Recovery Task Force has proposed the notion of “15-minute cities” whereby all city residents can meet their essential daily needs through either walking and riding a bike and already this concept is being adopted in major cities such as Milan (Italy) and Paris (France) [40].

3 Sustainable mobility policy

3.1 Narratives to guide sustainable mobility policy design

An essential question for policymakers is how to leverage the events surrounding the COVID-19 crisis to help avoid the long-term lock-in of a sociotechnical system of GHG-intensive, car-based transportation. In order to avoid such a system, the key factors that underpin GHG emissions in transportation and provide tangible definition to the notion of sustainable mobility need to be considered. The CUTE (Comparative study on Urban Transport and the Environment) matrix provides one framework for addressing such considerations and it includes both strategies and policy instruments for achieving sustainable mobility [41]. The strategies, which are transport demand reduction, car use reduction, alternative transport mode

improvement, road network improvement and vehicle technology improvement, are summarized into the ASI Framework (**A**void unnecessary travel, **S**hift to lower-carbon transport modes and **I**mprove transportation emission intensity) [42, 43]. The policy instruments, elaborated later in this paper, are categorized according to their focus on technologies, regulations, information or economics. Very similar to the CUTE framework, the ASIF framework shows clearly the importance of transportation **A**ctivity, Modal **S**tructure, Energy **I**ntensity and **F**uel Carbon Intensity [44]. Both ASIF and ASI align very well with Banister's sustainable mobility paradigm [19], which outlines the following elements:

- **Reduce travel activity** through innovations such as tele-working, tele-conferencing, and internet shopping. This focus also shifts the attention from technological substitution pathways to a wider range of carbon reduction pathways, which also explicitly address mobility demand;
- **Reduce travel activity** by shortening trip lengths through (non-transport) innovations such as compact cities and smart cities;
- **Shift modal structure** to reduce car use (conceptualized as changes in the relative size of regimes).
- **Reduce energy intensity and fuel carbon intensity** by improving the energy efficiency of transport modes and technologies, either through accelerated incremental innovation or radical component substitution;

Considering these frameworks, one can see that the notion of sustainable mobility through GHG emissions reduction is underpinned by reducing transportation activity, reducing energy intensity, reducing fuel carbon intensity and shifting modal structure to sustainable means of transportation. It is therefore useful to consider sustainable mobility narratives that

encompass technologies and social practices that address these factors by mitigating the need for car use, encouraging modal shifts in transportation from private to shared transport and supporting the broad deployment of low-carbon personal transportation, particularly electric vehicles (EVs). Narratives are valuable in that they do not just convey descriptive concepts, but rather establish visions that can influence how sociotechnical transitions, such as sustainable mobility, can be achieved. Holden et al. have proposed three such sustainable mobility “grand narratives” [20]:

- **Electro-mobility** – replacement of fossil fuel based vehicles with electric vehicles fueled by clean energy.
- **Collective transport 2.0** - increasing utilization of both public transport and cars, the latter being shared mobility.
- **Low-mobility societies** – reducing the number and length of trips by cars (and planes).

The impact of COVID-19 on the collective transport narrative is clearly negative given concerns for social distancing to mitigate COVID-19 transmission as well as negative perceptions of public transportation relative to private transportation following events, such as terrorist attacks, that make public transportation seem risky [42, 45]. This is illustrated by the transportation modal shifts that occurred after a series of bombs exploded in three London underground trains and one bus, killing and injuring more than 750 people in July 2005 [32].

Alternatively, the impact of COVID-19 on the low-mobility societies narrative should be mostly positive given the rapid evolution and uptake of ICT-enabled work, commerce and socialization from home during the crisis [46] and the finding that workers are in many cases more productive working at home rather than in the office [47]. The impact on electro-mobility

is perhaps neutral, although increased salience of global crises resulting from COVID-19 may stimulate the uptake of green technologies. given the role they play in climate crisis mitigation [48]. Already EV sales are expected to outperform sales in the rest of the auto industry in 2020 despite the recent significant drop in oil prices due to supply/demand imbalances caused by COVID-19 [49], supporting the notion that consumer acceptance of EVs will increase as a result of COVID-19 [13].

In recognition of the stated opportunity for translating the COVID-19 pandemic into a positive catalyst for change, policymakers can leverage stimulus funding, deviations in societal habits and perceptions triggered by COVID-19 to effect long-term transportation changes that can positively influence GHG mitigation efforts. Based on the information presented, low-carbon transportation (e.g. electro-mobility) and reduced travel (e.g. low-mobility societies) have positive momentum that can be further amplified. Public and shared transportation (e.g. collective transport), on the other hand, should be protected to remain viable and solvent, particularly for disadvantaged segments of society that rely on it to carry out essential daily activities [50].

3.2 Sustainable mobility policy options

There are a number of regulatory, economic and information policy instruments that can be implemented in an effort to achieve sustainable mobility and support one or more sustainable mobility narratives. In the context of sustainability transitions, these measures can serve to stimulate or accelerate niche technologies or practices, destabilize incumbent regimes, address the impacts of such destabilization, coordinate regimes or tilt the landscape [51]. Table 1 outlines a non-exhaustive, but nonetheless informative, selected set of sustainable mobility policy

instruments that serve to achieve a number of these policy objectives [18, 41, 52]. A mapping of these instruments to their related sustainable mobility narratives is also provided.

Table 1: Sustainable mobility policies and intersections with grand mobility narratives

			Narratives		
			Electro-mobility	Low-carbon societies	Collective transport 2.0
Policy Instruments	Regulatory	ICE vehicle standards (mandatory) (e.g. more rigorous fuel economy standards)	√		
		ICE vehicle access restrictions (e.g. vehicle-type bans, license plate restrictions)	√	√	√
		Mobility services regulations (e.g. sustainable mobility licensing)	√		√
		Operational codes (e.g. speed limits, right-of-way regulation)		√	
		Planning & infrastructure design (e.g. parking space reductions)		√	√
		ICE vehicle ban or planned phase out	√	√	√
	Economic	Investment in sustainable mobility R&D	√		
		Investment in electric charging and/or hydrogen refueling infrastructure	√		
		Investment in active/soft mobility options		√	
		Investment in public mobility technologies			√
		Financial incentives (tax breaks, tax exemptions, “cash-for-clunker” scrappage schemes, or other financial subsidies for EVs)	√		
		Investment in ICT infrastructure		√	
		Reduction of public transport fees			√
		Elimination/reinvestment of fossil fuel subsidies with reinvestment of the saved funds in subsidizing public transport and ZEVs purchases	√		√
		Road pricing	√	√	√
	Information	Standards (voluntary) (e.g. efficiency labelling)	√		
		Promotional campaigns for low-carbon and public transportation	√	√	√
		Awareness campaigns for the need to mitigate the chances of global crisis, like COVID-19 now and climate change in the future	√	√	√
		Awareness campaigns for the cleanliness and safety of public transportation			√

The analysis presented in Table 1 reflects the notion that a sustainable mobility transition is supported by policies that stimulate the emergence and diffusion niche-innovations while enhancing selection pressure on the established car-centric transportation regime. Within this context, robust policy measures cut across all of the sustainable mobility narratives and hence ICE vehicle access restrictions, road pricing and ICE car bans are particularly important forms of economic and regulatory policy.

While road pricing that disincentives the use of personal ICE vehicles is considered one of the highest potential means of achieving CO₂ emissions reductions in transportation [53], an outright ICE car ban is obviously a more direct means of achieving transportation sector sustainability. The phase out of ICE cars is indeed a strategy already being adopted by nations, sub-national regions and cities [54] and serves as an important regulatory option for achieving net-zero carbon cities [55] given that the additional considerations are made:

- In terms of timing, ICE vehicles should be fully banned no later than 2035 or 2040 to align with deep GHG-reduction goals [54].
- Ideally cars bans would be announced and implemented with enough conviction to signal the car industry to channel innovation efforts into EV (including battery electric and fuel cell) technology and to give stakeholders sufficient time to plan and adapt to the transition [56, 57]. Alternative modes of transportation, particularly active mobility and public transportation must be readily available and so complimentary economic policies may need to be implemented. The power sector must also transition to clean and renewable energy or else electrification of transport will have little positive impact on sustainability.

- In parallel to planned ICE car bans, public transportation and Transportation Network Companies (TNCs) should be required to transition towards EVs as Lyft has recently announced [58]. This will better ensure overall transportation system sustainability. Buses are already expected to be at the forefront of electrification [24] and so this is actually a reinforcing need.

This set of considerations related to the phasing out of ICE cars reflects a broader implication for sustainable mobility policy. Namely, policies targeting one mobility regime, such as cars, will often impact other mobility regimes, such as public transportation, as well as parallel regimes that affect mobility demand, such as city spatial planning [22]. Hence, policy design should be undertaken with the transport system as a whole in mind.

Regarding the other noted policy instruments, investment in clean energy R&D, including technologies that are key elements of sustainable mobility niche-innovations like batteries and hydrogen, is a widely supported measure with long-term impacts [9, 59]. To this point, the role that EVs can play in the proliferation of green energy extends beyond the transportation sector when we consider their batteries as distributed energy storage resources. Comprehensive examinations of vehicle-to-grid business models and markets suggests that even the existing batteries in vehicles —without adding any new future vehicles to the mix — could make for a very large, and underutilized, resource for distributed energy storage, one greater than the size of the national electricity grid in most countries [60]. The global stock of light-duty vehicles around the world could be converted and transformed into an incredibly large source of energy storage, helping further facilitate renewable energy diffusion, or the coupling of mobility systems with lower-carbon fuels, such as electricity.

From a more near-term perspective, investment in public mobility technologies and services that will enhance the attractiveness of public transport is critical simply to mitigate the potential for long-term damage to public transportation systems resulting from social distancing requirements and fear of disease spread via public transport [33, 34, 40, 61]. Specific investments may include:

- Direct government purchasing of electric delivery vehicles, buses, taxis, rideshare vehicles, and all publicly owned vehicles.
- Mobility-as-a-Service (MaaS) platforms with seamless connectivity among transportation modes (e.g. rail, rideshare vehicle, bicycle, scooter). MaaS has the potential to benefit both public and private shared transportation simultaneously [62].
- Autonomous (and perhaps shared) EVs (lack of driver enhances social distancing).
- First and last mile mobility for accessing public transport.

A very timely economic policy instrument is fossil fuel subsidy reform. The decline in fossil fuel prices linked to the COVID-19 pandemic provide an opportunity to reduce or eliminate fossil fuel subsidies without increasing end-use prices [3].

The critical role of information policy instruments should also not be overlooked. For any policy mix to be successful, public engagement is essential to reduce the likelihood of resistance [63, 64] and is at the core of achieving socially and environmentally “responsible transport” post COVID-19 [65]. In this regard, the following may be particularly important with applicability across each of the sustainable mobility narratives:

- Campaigns that promote low-carbon and public transportation with particular emphasis on how vehicles emissions, particularly NO₂, are linked the severity of COVID-19 symptoms [66].

- Campaigns that reinforce public perceptions that the COVID-19 pandemic parallels in severity the potential impacts of climate change and hence the need for low-carbon and public transportation in the long run [48].
- Campaigns that raise awareness of cleanliness and safety protocols implemented for public transportation.

4 Discussion: choosing a policy mix to protect and enhance sustainable mobility in the COVID-19 era

Any policy mix ultimately put in place in response to COVID-19 should position maintain and promote public transportation utilization, catalyze the deployment of low-carbon transportation, promote walking and cycling to the extent possible, and directly discourage the use of internal combustion engine (ICE) private cars. It should further build on climate beneficial and potentially long-term behavioral changes and perceptions induced by the events surrounding COVID-19 and mitigate the negative impacts of these behavioral changes and perceptions on the use of public and shared transportation [67]. A sufficient number of policy instruments are available to allow nearly any policy to position priorities based on the ASIF and ASI frameworks discussed in this paper. This is entirely consistent with the previously discussed sustainable mobility frameworks and narratives as depicted in Figure 2 and elaborated as follows:

- **Avoid** unnecessary transportation volume - refers to activities such as working from home and shopping from home are in this category. However, transport policy per se only has a limited ability to reduce the need to travel and other, complimentary measures will be needed.
- **Shift** transportation norms and practices - includes support for public transport as well as emerging modes of transportation like ridesharing. Cycling and walking are also relevant.

- **Improve** transportation systems – considers increasing the efficiency of transportation infrastructure and fuels to make them more energy-efficient and environmentally friendly. Electric vehicles, emissions standards, and even campaigns that support eco-driving are relevant.

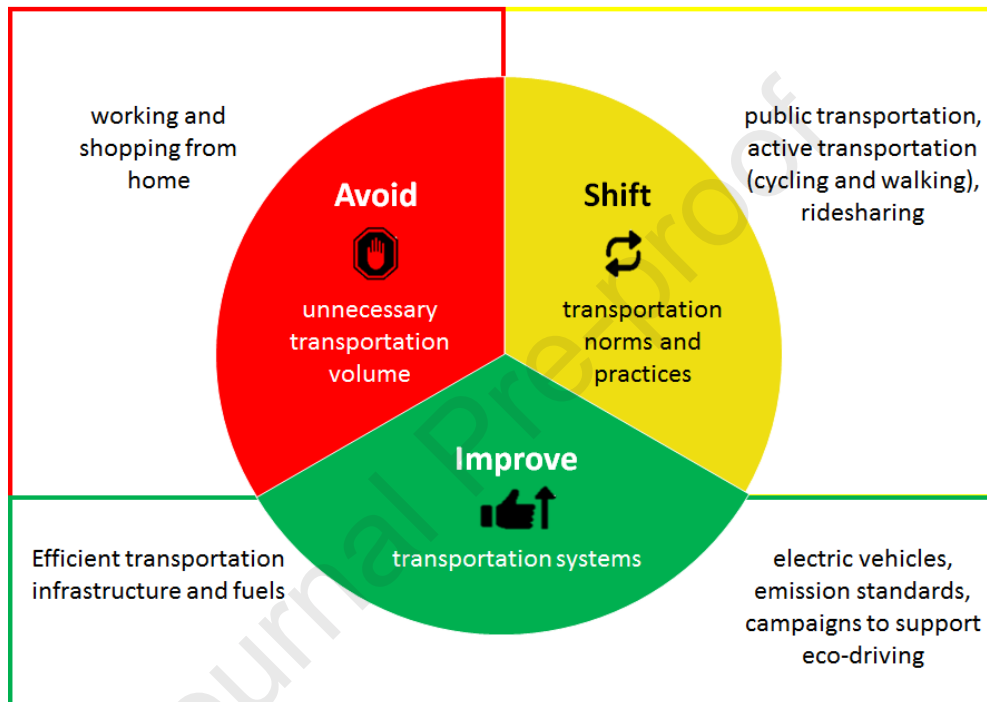


Figure 2: An “avoid-shift-improve” policy mix for achieving sustainable mobility

The COVID-19 pandemic, however, makes the achievement of these objectives complicated. Even in times of no crisis, common barriers to overcome for sustainable mobility policy implementation include resource barriers (financial and physical), institutional and policy barriers, social and cultural barriers; legal barriers, side effects (making the implementation too complicated), and other (physical) barriers [68]. Given the COVID-19 situation, additional considerations that take a holistic perspective the entire passenger mobility sociotechnical system [22] and support coordination across multiple mobility regimes, as well as those related to mobility, [51] may be all the more important for successful policy design and implementation:

- **Consider local context:** each town, city, state and/or country has a unique political economy, form of government and economic situation that can make different sustainable mobility narratives more or less relevant and related policy options more or less viable. The COVID-19 crisis and related fall in energy prices makes certain policies, like energy subsidy reform, universally attractive. Many policies, however, need to be evaluated carefully for the contexts in which they would be implemented. As shown by Sovacool and Griffiths, local culture can play a significant role in the success of policies aimed at supporting low-carbon technologies and practices [63, 64].
- **Focus on urban environments:** densely populated cities have been particularly hard hit by COVID-19 [40, 61] and this creates a dilemma for the move toward zero-carbon cities that are clean, compact and connected [55]. The number of people living in cities is growing rapidly, rising from 30% of the world's population in 1950 to 55% of the world's population today, to a projected 68% by 2050 [69]. Up to three quarters of CO₂ emissions from final energy use can be attributed to urban areas and so policies need to focus on sustainability in cities [55].
- **Provide enabling governance:** urban planning must align with transport planning given the interconnected nature of transportation and urban environments. Coordination of stakeholders across domains (e.g. from different ministries and departments) makes it easier to develop coherent, complementary policies and plans. This is very important given that political, cultural and organizational barriers tend to dominate the challenges for sustainable mobility policy [18].
- **Eliminate or modify existing contradictory policies:** in addition to the implementation of new policy measures, existing policies that are harmful or contradictory to new

initiatives must be identified and eliminated. Examples of such policies include fuel subsidies, tax breaks on ICE cars and minimum parking requirements. As discussed in this work, stimulus spending plans proposed by G20 economies are expected to have a net-negative environmental impacts and this is largely because of such contradictory policies being implemented [8, 10].

- **Provide sufficient funding:** in addition to new stimulus funding, national transportation budgets and infrastructure spending priorities should shift from building roads and infrastructure that benefit private car use to public transportation, walking, and cycling. New connectivity infrastructure, like 5G with strong cybersecurity, should be supported to enable work and commerce from home.

Cities are a focal point for assessing COVID-19 impacts on sustainable mobility as they present a diversity of archetypes and local contexts [70] with fragilities that have been exposed by the virus spread [61, 71]. Cities are also central to the UN Sustainable Development Goals (SDGs), being the direct focus of SDG 11 (Sustainable Cities and Communities) and having impact on broad range of other SDGs due to the crosscutting nature of urban issues [69]. Further, sustainable mobility transitions in cities have a distinct sociotechnical context that must take into consideration a myriad of factors discussed in this paper, including land use planning, ICT infrastructure, regulation and pricing, public awareness, behavior change and local planning cultures [19, 72]. Active mobility as well as shared and public transportation are key innovation opportunities for sustainable mobility in cities that have been significantly impacted by COVID-19. Social distancing requirements have put shared and public transportation in cities in jeopardy, including applications such as mobility-as-a-service and peer-to-peer ridesharing [73], while at the same time, catalyzing the uptake of active mobility in the form of walking and

cycling [35]. Particularly concerning is renewed interest in private car purchases resulting from the concern of COVID-19 spread and negative attitudes towards public transportation. Surveys in China, which was the first country impacted by COVID-19, interest in private car purchases has surged while interest in bus/metro use has plummeted [74]. Further, those interested in private car purchases are most interested in ICE SUVs, which are extremely damaging to the environment [74]. This suggests that fear of virus spread is perhaps reshaping functional automobility paradigms such that cocooning and fortressing are becoming more prevalent and can diminish the perceived importance of environmental stewardship [16]. This, in turn, could potentially have an environmentally negative impact on the norms of automobility and expectations of children growing up in the COVID-19 era given that children seem to prefer the same automobility regime in which they grew up [75, 76]. Figure 3 plots the most favored brands of cars among a recent survey of school children and shows that Tesla, the current icon of fully battery electric, sustainable vehicles, was recognized by the children but with much less popularity than well-known luxury and performance car brands. Indeed, approximately 75% of the surveyed children support the current sociotechnical system of automobility, illustrating the stated concerns regarding environmentally damaging automobility paradigms that may strengthen because of COVID-19.

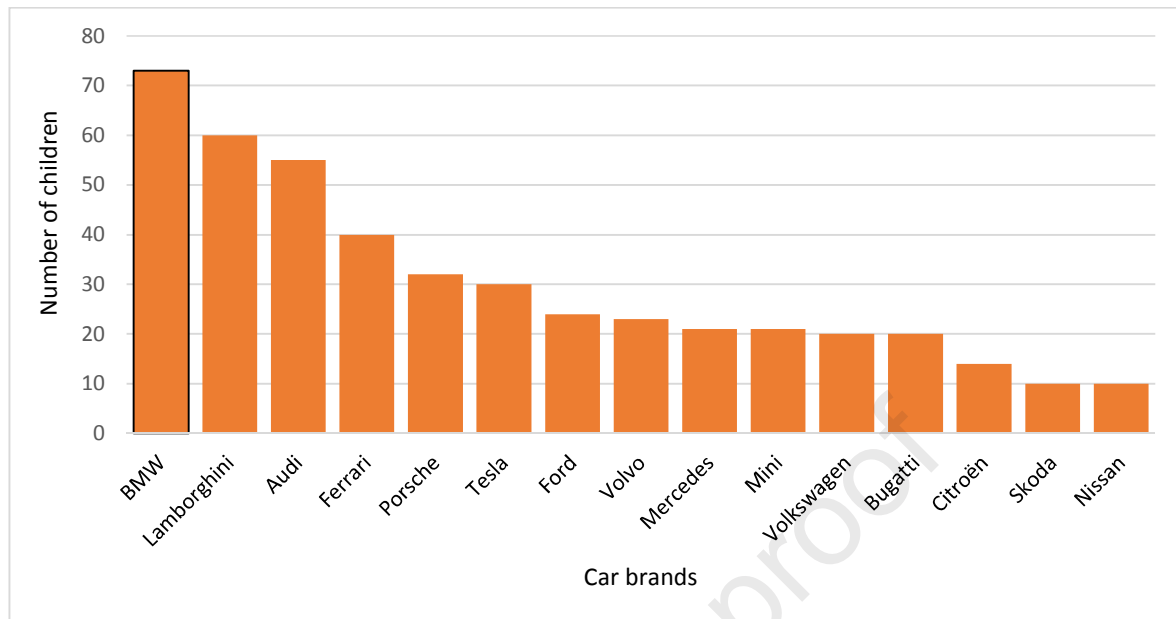


Figure 3: The most popular car brands among a survey of schoolchildren in Denmark and the Netherlands. The figure excludes 25 less frequently mentioned other brands ($n=83$), children who mentioned a type of vehicle instead of a model or brand, like a 4x4 ($n=23$), and inconclusive answers ($n=28$). Source: [75]

5 Conclusion and Policy Implications

This paper has highlighted an array of opportunities and challenges for sustainable mobility as the world attempts to recover from an unprecedented global pandemic. From the perspective of sociotechnical transitions, COVID-19 has created a landscape shift that creates potential opportunities for niche sustainable mobility innovation to emerge into mainstream adoption and multiple mobility regimes and regimes that affect mobility demand, such as spatial planning and work, to intersect in ways that support sustainable mobility. Key landscape developments are changes in behaviors and perceptions due to lockdown measures implemented to curtail the spread of COVID-19, a significant drop in energy prices due to supply/demand imbalances triggered by COVID-19 and massive global economic stimulus being deployed for recovery from the economic impacts of COVID-19. We have used a sustainable mobility

narratives framework to consider policy mixes that can stimulate a transition to sustainable mobility given these landscape developments.

Analysis of sustainable mobility policies and policy instruments relative to three narratives (electro-mobility, low-carbon societies and collective transport 2.0) suggests that a move toward car-free (particularly ICE cars) transportation via regulation and pricing and complimented by information campaigns could be an effective strategy. Further, fossil fuel subsidy reform would be timely given the dramatic decline in energy prices recently experienced.

These policy instruments, however, require tailoring to local context and cross-sector coordination in order to be effective. Cities or urban environments, broadly speaking, are a key context for policymakers given the complex systems that cities have become and their importance to global growth, energy consumption and climate change. In the city environment, the potential for COVID-19 concerns to stimulate a cocooning or fortressing automobility paradigm, would be highly detrimental given that even zero-carbon vehicles would create unsustainable traffic if public transportation were completely abandoned (or unavailable). The combination of work and commerce from home and active transport also cannot provide a complete solution to the abandonment of public transportation. As illustration of this point, London, New York, Paris and Tokyo each leverage metro and bus transportation to accommodate 5 to 10 million daily trips [35] and so no amount of work from home, walking and cycling can realistically replace public transportation in these cities. In very hot regions of the world, walking and cycling are not even an option for much of the year.

Beyond the impact on cities, the ingraining of automobility paradigms with potentially negative environmental consequences may adversely affect the sustainability of children's future

mobility choices. Hence, any sustainable mobility policy mix must make the protection of public transportation of key element and take into consideration the fact that policies implemented today may have long-term ramifications.

We have highlighted the need for strong, coordinated governance and sufficient funding to enable a broad sustainable mobility transition. The IEA has suggested that global economic stimulus for sustainable mobility be focused on encouraging consumer purchase of more efficient new vehicles, particularly EVs, improving urban infrastructure, expanding high-speed rail networks and supporting related R&D and innovation opportunities in batteries and hydrogen [3]. The expected outcomes of suggested investments are job creation, economic growth, and improved resilience and sustainability. The IEA's proposal as well as Green New Deals in the US, Canada and Europe [77-79] make compelling economic cases to leverage financial stimulus for combatting climate change.

Stimulus packages, however, are insufficient by themselves to promote sustainability mobility. These proposals run the risk of failing to recognize the critical need for tailored policy mixes that translate investment into successful actions. With substantial economic stimulus becoming available, policies properly tailored to local context can indeed support the transition to sustainable mobility that will help mitigate the likelihood of a future climate crisis that matches or exceeds the devastation caused by COVID-19. As part of national COVID-19 stimulus responses, a variety of transportation policy measures are being implemented globally with G20 countries alone proposing more than 70 sustainable mobility policies at national or subnational levels as of November 2020 [80]. The following sample is reflective of sustainable mobility policy measures being implemented globally [1]:

- Electric vehicle or efficient vehicle incentives - China, European Union, Italy, Spain, United Kingdom
- Cash-for-clunkers - France, Spain
- Public transport fleet modernization - European Union, Germany, South Korea
- EV production support – Germany
- EV charging infrastructure - European Union, Germany

Complimenting such measures aimed at stimulating clean personal and public transport are those that specifically target active or soft mobility. The EU has already invested more than €1 billion on cycling infrastructure across 94 European Cities since the outbreak of Covid-19 [81]. Among the EU countries, Finland spent the most in cycling infrastructure (€7.76 per person), followed by Italy (€5.04 per person) and France (€4.91 per person) [82]. In Mexico City cycling lanes have been expanded and in Colombia the Medellin “eco-city” clean transport package will expand bike lines by up to 50% [80]. Similar measures are expected to continue to be implemented globally as cities target “green and just” recoveries from the COVID-19 pandemic [40].

In time, a significant research opportunity will be present to study and evaluate the actual impacts of stimulus programs implemented and the extent to which thoughtful and context-specific policy design and enactment was able to achieve a sustainable mobility transition.

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- Defines culture as the ideas, customs, and social behavior of a particular people or society
- Shows how culture can act as a barrier, impediment, and obstacle to low-carbon transitions across 28 countries
- Reveals cultural barriers to eco-driving, automated vehicles, and ridesharing
- Illustrates cultural barriers to solar home systems, cleaner/improved cookstoves, and efficient buildings
- Suggests the positioning of culture in policies, interventions and future research focused on supporting low-carbon energy transitions

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Declaration of interests

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.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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