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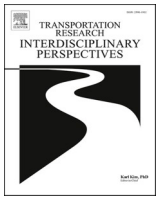

Towards truly sustainable mobility

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A B S T R A C T

Although sustainability is an important goal in transport policies, the focus is often on environmental sustainability, mostly ignoring economic and social aspects of sustainability. However, transport has important impacts on various sustainability elements. In this commentary, I first give an overview of how transport is related with four pillars of sustainability. Second, I describe how transport can be made more sustainable (in the broad sense of the word) by means of (i) technology and (ii) planning and policy. Third, I discuss the uncertain and potentially undesired effects of these new technologies and policy measures on sustainability. Finally, future research on how to make transport more sustainable is discussed.

Sustainability

Sustainability is a broad concept. Although it is most often linked to environmental elements, it can also be associated with economic and social aspects (Purvis et al., 2019). Despite sustainability often being subdivided into three pillars – environmental, economic, and social – I will apply the four pillar structure of sustainability which also includes human sustainability. Environmental sustainability refers to the protection of our planet's natural environment. Economic sustainability refers to creating efficient systems and services, thereby improving people's standard of living. Social sustainability refers to equity and equal access to elements such as education, work, and healthcare. Human sustainability refers to people's (physical and mental) health, well-being and quality of life. Human sustainability is often regarded as part of social sustainability. However, as transport may have varying effects on social and human sustainability, the four pillar structure of sustainability is used in this article. These four dimensions are closely related to the United Nation's Sustainable Development Goals (SDGs), which are currently often used as guidelines by local, regional and national policymakers. For instance, environmental sustainability is linked to SDGs 13, 14, and 15 (Climate action, Life below water, and Life on land), economic sustainability is linked to SDGs 8 and 9 (Decent work and economic growth, and Industry, innovation and infrastructure), social sustainability is linked to SDGs 4, 5 and 10 (Quality education, Gender equality, and Reduced inequality), and human sustainability can be linked to SDGs 1, 2, and 3 (No poverty, Zero hunger, and Good health and well-being) (United Nations, 2022). All the different types of sustainability are linked to transport, which will be described below.

Transport and sustainability

Transport has an important impact on environmental sustainability. Transport contributes significantly to air pollution. In the EU, for instance, 28.5 % of the total greenhouse gas emissions comes from transport, mainly from road transport (EEA, 2022). As a result, transport has an important impact on climate change. Additionally, the transport sector is the only sector with increasing levels of greenhouse gas emissions, thereby gradually increasing its share. Transport can also result in water and soil pollution as oil, fluids and dust from tyres and brake pads are washed off by the rain in our soil and water, while dense road networks in many parts of the world have negative impacts on ecosystems and biodiversity (Coffin, 2007; Handy, 2013).

Transport also impacts economic sustainability. Good transport infrastructure and public transport networks are needed for people to travel to work or to transport goods. However, transport systems may not always be very efficient, especially during peak hours. From a mobility perspective, people often lose a considerable share of time due to traffic congestion or public transport disruptions (Yap and Cats, 2021; https://www.tomtom.com/traffic-index/), time that cannot be spent on other valuable activities (e.g., leisure/social activities) (Stutzer & Frey, 2008). Efficient transport systems may result in seamless travel (travel without disruptions), positively affecting the travel experience.

Transport is strongly related with social sustainability. Transport is needed to reach out-of-home activities such as work, school, and healthcare. However, not everybody has the same level of access to these destinations. Low-income households may have fewer travel options (e.g., no car ownership), and may not be able to afford living in close proximity of their work or important public transport stations. As a result, they often have longer commute durations and spend a higher

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share of their available budget on travel. In some cases, transport disadvantage (no access to cars or public transport) may result in people not being able to participate in (desired) out-of-home activities, negatively affecting their quality of life (Lucas, 2012).

Transport can have a strong impact on human sustainability. Motorised transport contributes to air and noise pollution, which can result in various respiratory and cardiovascular diseases. Furthermore, around 1.35 million people get killed in traffic each year, making traffic accidents one of the top ten causes of death worldwide (WHO, 2014). Finally, driving – as a sedentary activity – increases chances of being overweight and having obesity (which in turn can cause other diseases) (Frank et al., 2004). Transport can also impact well-being. Trips with long durations, and with motorised travel modes (mainly in case of congestion and crowding), are often negatively perceived, thereby possibly negatively affecting the performance of – and satisfaction with – the activity at the destination (De Vos, 2019). Since travel time is often regarded as wasted time, and time that cannot be spend on (rewarding) activities, long commute times can negatively affect life satisfaction (Stutzer and Frey, 2008).

Making transport more sustainable

Technology

Technology can help in making transport more sustainable. Electric mobility, including electric vehicles (EVs), e-bikes and e-scooters, have the advantage of not having tailpipe emissions. Furthermore, the life-cycle carbon footprint of EVs (including manufacturing, operation, and decommissioning), is lower than for conventional cars (Farzaneh and Jung, 2023). Hence, increased electric mobility can significantly improve air quality, especially in cities, and thereby positively affect environmental sustainability and human sustainability. Autonomous vehicles (AVs) may improve human sustainability as they are regarded as safer (due to collision avoidance technologies) thereby resulting in fewer traffic accidents and fatalities. Due to fewer accidents, but also smoother traffic flows (as AVs can safely drive close to each other), congestion will drop, enhancing economic sustainability. Additionally, the use of AVs will result in less parking space needed, especially in urban areas, since AVs can drive themselves to parking lots at the edge of the city after dropping somebody off, or they can be used by other people in case of shared AVs. As a result, this space can be used to create better infrastructure for pedestrians and cyclists, or high-quality public spaces, thereby improving the liveability of cities (Rahman and Thil, 2023; Soteropoulos et al., 2019). Autonomous public transport (already applied in multiple metro systems worldwide) can enhance safety, frequency, and reliability (e.g., due to platform screen doors, increased rail efficiency, and decreased levels of human error) (Yuen et al., 2022).

Shared micromobility, such as shared e-bike and e-scooter schemes, could improve social sustainability, as they could serve as first and last mile travel modes, thereby improving access to public transport and destinations reachable by public transport (Oeschger et al., 2020). Transport can also be made more equitable (i.e., improving social sustainability) by certain inventive technologies, such as cable car networks, which have proven to improve accessibility for low-income neighbourhoods in South American cities (Bocarejo et al., 2014). Smartphone app-based mobility services, such as Mobility as a Service (MaaS) and ridehailing services, could make travel more efficient and convenient, partly because these on-demand services can be modified to the travellers' needs (e.g., Kamargianni et al., 2016).

Planning and policy

Apart from technology, spatial/transport planning and related policies can also improve transport sustainability. Spatial planning concepts stimulating compact developments and mixed land use will reduce average travel distance and thereby discourage car use (Cervero and Kockelman, 1997). Together with a design stimulating active travel (wide/well-lit sidewalks, separated bicycle lanes and safe pedestrian/cyclist crossings), this may result in more walking and cycling, which in turn will reduce air and noise pollution, traffic accidents, congestion, and may improve travel satisfaction and equity (as active travel is accessible for most). Hence, various aspects of sustainability will improve. In a transit-oriented development, where compact, mixed-use neighbourhoods are developed around important public transport stops, people have easy access (on foot or by bicycle) to public transport in case activities are located outside walking or cycling distance, making car ownership unnecessary (Ibraeva et al., 2020). The related 15-minute city concept, in which most destinations would be available in people's neighbourhood and within 15 min of walking or cycling would improve social sustainability as more activities become accessible for those with limited travel options (Hosford et al., 2022; Willberg et al., 2023).

Vehicle access regulation policies may have positive sustainability outcomes. Low-emission zones (preventing or charging polluting vehicles in a certain area), road pricing schemes (charging drivers for using roads) and low-traffic neighbourhoods (limiting motorised through traffic), for instance, will most likely improve environmental, economic, and human sustainability, as air/noise pollution, traffic accidents and congestion levels are likely to drop (Börjesson et al., 2012; Yang et al., 2022). Finally, providing more and better public transport services in low-income neighbourhoods can improve access to important activities (e.g., education, work), and lower car dependence and travel time/money expenditure, thereby improving social sustainability (Tiznado-Aitken et al., 2021).

Uncertain and undesired effects

Although new technology and transport/planning policies are likely to have certain positive effects on sustainability, undesired effects may also occur. AVs, for instance, potentially increasing accessibility for people who are unable to drive (e.g., children, elderly, and disabled people), may not be accessible or affordable for all and may therefore increase transport inequality (Emory et al., 2022). Furthermore, AVs may result in more vehicle kilometres travelled if certain non-driving population groups switch to motorised travel, resulting in less active travel and physical activity (Kröger et al., 2019), potentially negatively affecting human sustainability. Additionally, AVs may contribute to urban sprawl as AV travel time may not be regarded as wasted time and people do not mind living further away from work, negatively affecting ecosystems and biodiversity (Rahman and Thil, 2023). Many effects of AVs on sustainability may depend on whether AVs will be privately owned or shared. Shared AVs will likely have less negative impacts on sustainability as they would be easier accessible and would result in fewer empty AVs driving around (Soteropoulos et al., 2019).

EVs, on the other hand, may not improve social sustainability as they may not be affordable for low-income households (Caulfield et al., 2022). Hence, subsidies may be needed, especially in light of the upcoming ban on sales of new petrol and diesel cars (e.g., in 2035 in the EU). Furthermore, EVs will not reduce congestion and travel time loss and therefore will not improve economic sustainability. As they do not involve physical activity, occupy ample road and parking space, and people generally do not enjoy car trips, the positive effect on human sustainability only seems to relate to better air quality (Jochem et al., 2016). This differs from e-scooters and especially e-bikes, which provide physical activity, do not result in time loss (because of congestion) and may result in more (distant) activities being accessible for a bigger group of people (Bourne et al., 2020). Despite shared e-scooters often been advertised as being complementary to public transport and a solution for the first and last mile problem, most studies indicate that e-scooter trips are actually replacing public transport and walking trips (Wang et al., 2023). Hence, it does not reduce the negative effects of car use on various aspects of sustainability. Furthermore, shared e-scooters may

	Environmental sustainability	Economic sustainability	Social sustainability	Human sustainability
AVs	?	+	?	?
Electric mobility	+	?	?	?
(Shared) micromobility	?	?	?	?
Vehicle access regulation	+	+	-	+
Urban/transport planning	+	+	?	+

Fig. 1. Hypothesised effects of transport technologies/policies on the four sustainable elements (+: positive effects; ?: uncertain effects; -: negative effects).

not contribute to equity as they are mainly available in wealthier neighbourhoods, and often more expensive than public transport (Mooney et al., 2019).

Policies such as low-emission zones and road pricing schemes may have negative equity effects, as low-income households often own polluting cars (and therefore can no longer (freely) access low-emission zones), and cannot afford to pay charges for using a road segment on a daily basis (Eliasson, 2016; Morton et al., 2021). Hence, accompanying measures such as improved public transport services, a scrappage scheme for polluting vehicles, or subsidies for non-polluting vehicles may be needed. Finally, planning policies stimulating compact, mixed-use developments (ideally in proximity of public transport) may attract high-income households and push away low-income households to neighbourhoods with fewer travel options, resulting in new equity issues (Padeiro et al., 2019).

Further research

The above sections indicate that certain transport technologies and policies will most likely have straightforward effects on sustainability aspects. For instance, electric mobility will most likely improve environmental sustainability (due to reduced air pollution), while urban planning policies will presumably improve human sustainability (due to lower levels of congestion and pollution, and higher levels of active travel and nearby activities). However, certain transport technologies/policies may have uncertain or even undesired effects on sustainability. For instance, the effects of AVs, EVs and shared micromobility on social and human sustainability are largely unknown, while vehicle access regulation policies may even have negative impacts on social sustainability (Fig. 1). In sum, future transport studies should not only focus on the effects of new technologies and policies on environmental sustainability, but also on economic, and especially social and human sustainability. Hence, interdisciplinary transport research is needed to generate valuable insights on how to create truly sustainable mobility.

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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