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Leveraging digitalization for sustainability in urban transport

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Abstract

Digitalization coevolves with and fosters three revolutions in urban transport: sharing, electrification and automatization. This dynamic poses severe risks for social and environmental sustainability. Only strong public policies can steer digitalization towards fostering sustainability in urban transport.

Social media summary

Public policies are central to rendering low-carbon smart mobility and avoiding problematic rebound effects.

1. Introduction

With urbanization and big data, two megatrends of the twenty-first century merge in the concept of the so-called smart city. Before we reach 2050, more than two-thirds of humanity will live in cities – and they will increasingly encounter the digitalization of cities, including the use of big data technologies, artificial intelligence and automatization (WBGU, 2019). The design of cities, including their digitalization, will be decisive in shaping greenhouse gas emission trajectories and climate change mitigation (Bai *et al.*, 2018; Creutzig *et al.*, 2016), will risk the spectre of social control and surveillance, questioning the right to the city (Harvey, 2003; Sadowski & Pasquale, 2015), and will provide both chances for and risks to social inclusion (Fossati, 2018; Reckien *et al.*, 2017). With the rapid rise of digital technologies, including artificial intelligence methods targeted for climate change (Rolnick *et al.*, 2019) and meeting unprepared regulatory environments, it becomes increasingly urgent to provide urban governance of digitalization that ensures that digitalization can help to provision public goods and environmentally beneficial outcomes. With this framing, this article agrees with the German Advisory Council on Global Change that digitalization is not an external upheaval to which we must adapt, but rather a dynamic process that must be shaped to deliver a transformation towards sustainable and low-carbon societies (WBGU, 2019).

Some policy-makers and businesses herald the smart city as the solution to high resource consumption and consumption footprints. High-tech smart devices 'everyware' enable instant digital self-awareness and the uptake of hyper-efficient solutions (Kitchin, 2014). Already today, smartphone applications provide access to free-floating shared vehicle fleets in cities from Berlin to Vancouver. Hundreds of thousands of bikes available instantly on demand fill Chinese cities, from Beijing to Kunming, and they have changed mobility choices for the better (Wu & Xue, 2017). Transportation network companies, such as Uber and Lyft, provide added mobility for car-free households and potentially reduce the need to own a car (Henao & Marshall, 2018). The high utilization of vehicle stocks in sharing services fosters electrification and automatization, two technological innovations associated with high capital but low usage costs (Fulton, Mason & Meroux, 2017). Automatization itself will heavily rely on big data for optimal dispatch and routing of vehicle fleets.

The smart city is not limited to urban transport. In the building sector, for example, combining spatially explicit data with neural network models enables the prediction of building energy demand (Silva, Leal, Oliveira & Horta, 2018). We argue here, however, that big data applications in urban transport are of particular relevance, as they have the capacity to transform urban mobility and lifestyles, with the potential to make them better or worse. Personalized geo-located user data pose particular risks for loss of privacy and autonomy on the one hand through the internalization of a 'big brother' mind-set, and on the other hand via substantial biometric surveillance and automated policing (Sadowski & Pasquale, 2015). Here, we build on recent ground-breaking academic work on the governance of smart mobility (Docherty, Marsden & Anable, 2018; Marsden & Reardon, 2018) and focus on the crossroad that digitalization encounters both for social sustainability and climate change. We call for urban regulatory action to steer digitalization towards sustainable outcomes.

2. Opportunities and risks of digitalization in urban transport

There is no doubt that big data and specific digitalization technologies provide opportunities for transport operators, planners and users (Davidsson, Hajinasab, Holmgren, Jevinger & Persson, 2016). Specific examples also demonstrate economic benefits. The consumer surplus of ride-sharing services is estimated at \$1.60 for each \$1.00 spent, providing notable benefits to consumers (Cohen, Hahn, Hall, Levitt & Metcalfe, 2016).

At the same time, however, several social and environmental risks emerge from the massive and mostly unregulated use of big data and artificial intelligence (Kitchin, 2014; Linkov, Trump, Poinsatte-Jones & Florin, 2018), and efficiency gains in mobility could be rendered meaningless by induced demand for additional mobility, the shift from transit and non-motorized travel to automotive travel, deteriorating urban quality of life and further increasing environmental footprints (Cohen & Cavoli, 2019; Wadud, MacKenzie & Leiby, 2016). The loss of privacy and individual autonomy leads to an increasing and digitalization-specific power concentration, where those who create digital footprints become reduced to data sources and objects to be controlled by those with the means to collect or analyse data (Manovich, 2011). Transportation network companies, for example, collect vast amounts of data that help improve their profitability, but these data commonly are not shared with transport planners or researchers (Castiglione *et al.*, 2019). Ever fewer people can exert greater control over ever more people with both soft habitual nudges and hard surveillance. The ambition of the Chinese government to control their populace with social scoring cards makes this risk evident. Jaywalking, among many items, is surveilled and leads to negative scores. The nudging of Uber drivers to drive for longer times than intended is another example (Scheiber, 2017). Hacking of autonomous vehicles and smart appliances at home poses another obvious risk. While automatization creates new jobs in computer science, it can also generate loss of employment and status in other industries. Conservative estimates suggest that approximately 6–12% of all jobs are at risk of automatization, increasing pressure primarily on lower-paying jobs (Arntz, Gregory & Zierahn, 2016). Automation might also compromise the working ethos and social identity of certain occupations, such as taxi drivers, leading to social dissatisfaction.

The application of big data and artificial intelligence also impacts environmental sustainability. Big data methods revolutionize the research on cities worldwide, providing the quantitative foundations of an emerging global urban sustainability science, with direct applications for urban planning (Creutzig *et al.*, 2019). Preliminary examples and state-of-the-art research demonstrate that big data, at least in principle, can generate environmental benefits in urban transport. Flexible bike and car sharing has the potential to make urban transport more efficient and less dependent on owning a car. Studies of Lisbon and Berlin show that if travel demand should remain unchanged, sharing strategies could reduce the number of cars by more than 90%, also saving valuable urban space for human-scale activity (Bischoff & Maciejewski, 2016; Martinez & Viegas, 2017). Car-sharing studies demonstrate that public (autonomous) ride-sharing systems could substitute for private cars, with beneficial effects on reducing congestion, air pollution and greenhouse gas emissions.

However, even environmental benefits are not obvious, and big data, machine learning and automatization strategies could backfire. Surveys demonstrate that users often take free-floating car-sharing services as a substitute for public transit, and much less as a means to replace their private cars (Herrmann, Schulte & Voß, 2014). A case study of Djakarta shows that flexible motocycle sharing at best is neutral to overall greenhouse gas emissions if substitution effects and deadheading are accounted for (Suatmadi, Creutzig & Otto, 2019). Car sharing with automated vehicles could even worsen congestion and emissions by generating additional travel demand (Rubin, 2016). Some 22% of all trips travelled with Uber and Lyft would have been travelled by transit, 12% would have walked or biked and another 12% would not have travelled at all (induced demand) (Henao & Marshall, 2018). Travel time in autonomous vehicles can be used for other activities, but driving and travel costs are expected to decrease, which most likely will lead to additional demand for auto travel (Moeckel, 2017) and could even create incentives for further urban sprawl. Such developments would likely increase residential energy demand, commuting distances and the conversion rate of bio-productive land into low-density residential areas. More generally, the increased efficiency generated by big data and smart algorithms may generate rebound effects in demand and potentially compromise the public benefits of their efficiency promise (Gossart, 2015). Research on smart cities concerning both conceptual frameworks and empirical findings is still at a relative early stage, and it offers potential both for improvements and deteriorations (Kitchin, 2015). Similarly, automated driving offers the potential for substantial energy savings in a low-level setting, but also the risk of significantly increased demand for automotive travel and for resulting fuel consumption if automation sharply reduces the costs of drivers' time (Wadud *et al.*, 2016). We can only tentatively anticipate the overall effects of big data and artificial intelligence, and some unexpected dynamics will certainly surprise researchers and technology futurists. Nonetheless, the current understanding of this large-scale technological paradigm shift towards digitalization demonstrates two things: (1) the risks of socially and environmentally unsustainable outcomes is large; and (2) if properly managed, decision-makers can leverage big data, artificial intelligence and automatization for urban sustainability goals (Table 1).

3. The emerging governance of digitalization

Achieving these goals requires dealing with important trade-offs. For example, if big data remain unregulated, social risks could be realized and the potential environmental benefits or harms would become subject to hard-to-predict technological innovation rates and system dynamics, but unregulated digitalization could also bring first-mover advantages in developing new markets and

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Table 1. Risks, promises and policy options of digitalization (including big data technologies, artificial intelligence and automatization) for sustainability in cities.

Dimension	Promise	Risk	Public policy response	Example
Mobility and accessibility	Highly efficient transport; lower transaction costs; convenient options for the disadvantaged	Exclusion by technological or economic barriers; induced demand	Regulation to mandate inclusion; location- and effect-specific pricing; uniform service requirement	Access button calling a self-driving vehicle for all households mandated
Urban space	Freeing >90% of parking spaces for the public; reurbanization	Monopolization of transport space by autonomous vehicles and loss of public space; urban sprawl	Ensure promise of free space by parking management; regulate self-driving cars to free space for public life	Regulate shared mobility to serve the last mile but prohibit it as competition for public transit; urban vehicle-driving charges; strengthen zoning regulations
Urban planning	More efficient planning process; applicability in developing countries due to standardized data formats	Loss of control to private organizations	Foster developments in research and push data providers to publish data products	Sustainable, efficient real estate development using data from different sensors (call detail records, remote sensing, OpenStreetMap) at medium-scale resolution to keep data anonymous
CO_2 emissions	>50% reduction by shared vehicle use; low-level automatization could realize substantial energy savings	Increase in emissions by induced demand, deadheading and urban sprawl	Tax transport and land consumption externalities; flexible, progressive emissions standards	CO_2 tax on both fuel use and upstream emissions from producing vehicles
Health	High safety in motorized driving; reduced mortality from urban pollution	Out-crowding of inconvenient but healthy walking and cycling	Prioritize transport planning at human scale	Cities planned around walking and biking, such as Amsterdam
Data control and privacy	Personalization of data according to individual preferences	Loss of privacy and autonomy to private and public organizations	Mandate and control anonymization standards with explicit control options for users	Bike Citizens offers users the opportunity to donate data for bicycle infrastructure planning
Social identity	Ownership of city	Self-inflicted incapacitation due to loss of control and loss of agency	Citizen science with participation in creation and governance of data and urban design	BBBike: a crowdsourced platform for efficient and convenient bike routing

models of living. This model is best encapsulated by the US state of Arizona, which attracts the car fleets of companies invested into automated driving by providing unregulated access to Phoenix's roads, a pattern that is also likely to further lock in the structure of the automobile city. Tight social control managed by big data technology in turn might enable environmental benefits, but reduce the autonomy of individuals. The rule of the Communist Party in China closely resembles this model, where punishing polluters is enabled by a dense matrix of surveillance and big data technologies. But regulating both the social and environmental risks of big data is also possible. The EU, with its concern for both privacy and environmental issues, might be a candidate to implement comprehensive sustainable data regulation, but it shows only reluctant signs of moving in this direction.

The emerging transition research suggests that big data can not only support standard policies, but also facilitate the transition process itself. With digital citizen science, non-professional individuals are invited to join the production of knowledge and big data (e.g., by collecting, classifying and sharing acoustic or visual signals of urban spaces recorded with their smart phones), or groups of activist individuals generate new knowledge uninvited (Dickel & Franzen, 2016). The intended production of user-generated data is a performative act and can produce a self-association with the goals underlying research, a process related to social identification (Deaux, 1996). Different forms of citizen science and the sharing of results and visualizations with the public can produce relevant niche cultures, and hence also become the starting points of a transition towards sustainability. Through understanding environmental problems as social problems that affect everyone, the search for solutions must include broad environmental citizenship, with citizens actively defining research and the policy agenda in local settings (Irwin, 1995). Citizen science projects are particularly widespread in the environmental sector, where volunteers are involved with their mobile devices (e.g., to monitor air, light or water pollution at different locations). OpenStreetMap might serve as a best-practice example in the field of volunteered geographic information usage (Haklay, 2010; Haklay & Weber, 2008). It is an open-access database of street networks, buildings and public facilities around the world (www.openstreetmap.org) that is community driven. BBBike is a crowdsourcing project based on OpenStreetMap that provides free optimal bike routing for Berlin and 200 other cities worldwide (Lenz & Heinrichs, 2017). In the reality of the emerging field of citizen science, however, volunteers are much more likely to act as human sensors for data collection rather than as self-determined researchers, and it is important to learn from both failed citizen science projects and successful examples, such as BBBike, to make citizen science useful for the public governance of big data by empowering people. This includes fostering a public understanding of big data (Michael & Lupton, 2016).

Societal inclusion means having access to all provisioning systems (Luhmann, 1995). A growing body of sociological literature

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analyses the mechanisms of inclusion and exclusion in contemporary societies (Stichweh, 2016), but the crucial role that access to mobility has for inclusion in all other provision systems is often ignored. The issue was put firmly on the political agenda by the Social Exclusion Unit of the UK government that existed between 1997 and 2010. A 2003 study for the UK found that young people with driving licenses are twice as likely to get jobs as those without; that nearly half of 16–18-year-olds experience difficulty in paying for transport to get to their place of study; that almost a third of carless households have difficulties in accessing their local hospital; and that children from the lowest social class are five times as likely to die in car accidents as children from the highest social class (SEU, 2003). The report's proposal of an accessibility planning framework that would include a range of public services and organizations is equally relevant for managing digitalization for sustainability in cities. Such accessibility planning must also consider that cheap, on-demand, door-to-door transport via autonomous vehicles is not desirable, because it would discourage active modes of transport – walking and cycling – that have proven co-benefits in terms of health and climate (Shaw, Hales, Howden-Chapman & Edwards, 2014). The important leverage that local governments have to shift modal shares towards active modes is demonstrated in cities such as Copenhagen, where, in 2017, 62% of citizens chose to bike to work and study, while the relative risk of having a serious bicycle accident has decreased by 23% since 2006 (City of Copenhagen, 2017; Pucher & Buehler, 2017).

In times when governments around the globe are trying to reduce expenditure by seeking to increase efficiency and shrink administrative costs, the risk of not being able to set the right framework conditions for sustainable transport systems and being overtaken by technological developments and innovation in the private sector are considerable (Docherty *et al.*, 2018). Therefore, transnational institutions, like the EU, are crucial to regulating data ownership, preserve autonomy and privacy. But also governance of cities and human settlements play crucial and underestimated roles in implementing solutions for environmental sustainability. Most relevant big data are geocoded and develop their full potential in the specific spatial setting. In the context of big data, governance levels of localities (cities, towns, villages) can best implement concrete political action that can push urban communities to sustainability.

4. Three directions of action

We suggest three directions of actions for cities to make best use of big data and digitalization for sustainable urban transport that could be spearheaded by cities like Berlin (Box 1). First, municipal administrations should establish an officer for digitalization and sustainability, who is responsible for coordinating digitalization efforts across departments and who coordinates with external non-profit and for-profit partners (e.g., non-governmental organizations and app developers). For example, in Tel Aviv, a new position of Central Information Officer was established, promoting digitalization to achieve the following (Press, 2018): (1) better data integration and cross-department collaboration; (2) targeting communication to citizens; (3) bidirectional participative formats with citizens; (4) improved tracking of service use enabling targeting improvements; (5) providing a digital geographic information system for planning for all stakeholders; and (6) remain supportive of providing high-quality public spaces. Such a digitalization officer would immediately raise attention and bring policy-oriented focus to the topic. Public agencies should also consider making the license to operate a certain transport service, such as Uber or Lyft, contingent on the willingness to share (anonymized) user data (cf. Chase, 2015; Docherty *et al.*, 2018).

Box 1. Berlin as a testbed for big data and sustainability.

In Berlin, business, science and municipal policy are all developing rapid expertise and interest in the governance of digitalization of the urban transport. Berlin is an established centre for new sharing services for cars (car2go, DriveNow, Flinkster), bikes (nextbike, Mobike, LIDL-Bikes, Byke) and scooters (emmy, COUP). The Berlin-based Innovation Center for Mobility and Societal Change (InnoZ) not only analyses big data from sharing services, but also offers an app, called modalyzer, which transport users can use to record their travel patterns and donate their data explicitly and voluntarily for research and optimization of mobility services (Lugano, 2017). Similarly, Berlin-based Bike Citizens developed an app that allows users to map their own travel patterns and to provide them for urban planning and research purposes (Gössling, 2018). Academic institutions, and especially the Technical University Berlin, perform a multitude of studies on Berlin mobility transitions, inter alia with the agent-based transport model, MATSim, whose Berlin specification is open access (https://github.com/matsim-vsp/matsim-berlin) (Ziemke, Kaddoura & Nagel, 2019). Since 2011, the state of Berlin follows an open data strategy that gives practitioners and scientists extensive access to information about demography, infrastructure and transport. A popular petition effort successfully pushed for a new mobility law that provides new opportunities for low-carbon modes of transport, such as cycling, which has been ratified by the Berlin Senate. Importantly, the Berlin Senate aims to expand this mobility law with a new focus on digitalization. This will offer an opportunity to implement regulation and provide new digital platforms that facilitate sustainability in urban transport.

Second, municipalities and foundations should push for digital platforms that provide seamless integration of all mobility services, including bike sharing, taxis and public transport, to foster multimodal and sustainable transport. A seamless integration of services could result into a cooperative transport system based on human engagement and shared decision-making (Miller, 2013). These platforms should facilitate and reward the sharing of information to contribute to societal benefits generated with open data. Importantly, such services should be delivered as open-source code and as not-for-profit infrastructure. In addition, collaboration in identifying, collecting, generating and using data across stakeholder groups is key to delivering sustainable urban development (Paskaleva *et al.*, 2017). Blockchain technologies could enable decentralized payment services, keeping users in control of their data, as is currently being explored by the TravelSpirit Foundation (Lopez & Farooq, 2018) (it would be crucial, however, to control the immense energy demand of blockchain technologies and decarbonize its supply chain; Truby, 2018). Users could nonetheless choose to donate their data for purposes of public interest. Municipalities can use such geo-located data generated by mobility users and other sources to cost-effectively advance urban planning and transport infrastructure decisions (Toole *et al.*, 2015). Municipalities can also leverage their control over public spaces to obtain some control over the urban digital space. Our own modelling results suggest that relatively coarse resolution is sufficient for planning, thus allowing anonymized data encodings that abstract from individual users.

Third, digitalization strategies will develop their full sustainability potential in the interplay with traditional urban planning, especially for walking, cycling and efficient public transit. These modes enable face-to-face contact in public settings, which are, if well designed, a key ingredient to urban quality of life (Gehl, 2013) and enable a transition away from the fossil city (Bongardt, Breithaupt & Creutzig, 2010; Bongardt *et al.*, 2013). The sharpened focus on urban planning is particularly warranted in the case of autonomous vehicles, which, if left unregulated, might induce more traffic and compete with transit, biking and walking. To avoid this competition for passengers, autonomous vehicles could be limited to serve as last-mile connections for transit, acting as a complement to rather than a substitute for efficient mobility structures. If artificial intelligence and smart and low-carbon public vehicles can serve cities, space currently used for parking can be put to better use. To avoid rebound effects, pricing signals should limit harmful effects, such as congestion and greenhouse gas emissions (e.g., with inner city tolls and CO_2 or energy pricing) (Kaddoura, Bischoff & Nagel, 2018). Such pricing schemes may be more acceptable to users of shared mobility platforms (mobility as a service) than for privately owned vehicles, and they would provide a revenue stream for city governments. Infrastructure policies are equally relevant. To advance this agenda, however, key challenges in information integration (already done in products like Google Maps), fare and ticketing integration (technically feasible), operational integration (difficult), business model integration (very difficult) and regulation integration (extremely challenging) need to be overcome (Kamargianni, Li, Matyas & Schafer, 2016).

Successful governance of big data will bridge the gap between user control (e.g., decentralized payment with blockchain technologies) and data availability for public policies (e.g., data donations by users to municipalities to improve transport planning). There is no reason to either demonize or deify big data and artificial intelligence. There is, however, a need to encounter these technologies actively with measured policies and applications, leveraging their potential for urban sustainability and beyond. In the USA or Canada, we see the first urban labs led by tech companies like Alphabet or Microsoft emerging in which the concept of the smart city is being tested. However, politics is needed to strengthen the common good instead of entering into far-reaching public–private partnerships (Sadowski, 2017). Municipalities and other public agencies need to take responsibility and to start governing the data and technologies generated in their cities in order to reap their benefits and minimize their risks.

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