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Best of Both Worlds? The Potentials and Challenges of Implementing Sustainable and Smart Urban Mobility

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In recent years, many academic and technical discussions about cities have been shaped by two topics: sustainability and smartness. While these two areas are evolving, there are definitely common grounds to be found in discourses on sustainability and smartness. First of all, this is the realization that any comprehensive transformation of long-term, complex processes requires governance and integration of topics and institutions, and second, that there can be no uniform approach to successfully becoming more sustainable or smarter. However, different directions of development can be identified that may—or may not—go together. Urban mobility has to deal with different definitions of and approaches to sustainability and smartness too. A specific format developed during the transdisciplinary project "Neue Mobilität Berlin" (New Mobility Berlin, http://neue-mobilitaet.berlin/) addresses these questions. Research results suggest, for one, that there are very practical technical issues that complicate a transition from existing mobility systems toward more sustainable and smart ones. For another, the results suggest that a comprehensive sustainable and smart urban mobility system will need more integration and coordination. This contribution takes off from project findings and discusses implications for the implementations of and discourses on smart and sustainable urban mobility.

Keywords: sustainability, smartness, urban mobility, knowledge, governance

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INTRODUCTION

During the last two decades, many academic and practical discussions about cities were shaped by two topics: sustainability and smartness. It was only in the mid-1990s that comprehensive sustainable development became a mainstream urban issue, the Aalborg Charter of 1994 and the Agenda 21 processes being the most prominent examples (Bulkeley and Betsill, 2005; Beatley, 2014). Sustainable development and sustainability research usually refer to the so-called three pillars of sustainability (ecological, economic, social—Ott, 2009). These were initially promoted by civil organizations and NGO, local governments consequently committed voluntarily to sustainability (Alber, 2013). Since then, a large number of positive and—to a lesser extent negative—local experiences have been gained. Later on, non-binding supranational frameworks for sustainable urban and municipal development have been agreed upon (such as the Leipzig Charter for Sustainable European Cities, BMUB, 2007), the New Leipzig Charter EU 2020, or the United Nations, 2016).

Over the years, it has been acknowledged that sustainable development can and must be operationalized in different ways for different places (Elmqvist et al., 2019) in order to have an impact. In addition, there is widespread agreement that comprehensive sustainable development constitutes a multi-level challenge and is to be understood as a long-term and sometimes resource-intensive process (Krellenberg et al., 2016) with "highly complex real problems" (Zscheischler et al., 2014). With the growing number of case studies and experiences, three major developments can be observed regarding the implementation of sustainable development: (1) a general shift from hierarchically organized approaches to participatory, co-creative or even cooperative ones (Glass and Newig, 2019), (2) the importance of the production, exchange and dissemination of different forms of "socially robust knowledge" (Walter et al., 2007; see also EU, 2020), and (3) the need for a certain flexibility and openness in governance and implementation processes for sustainable development (Clune and Zehnder, 2018). In addition, it is being emphasized in a growing number of research that multi-level approaches are crucial, relating the effective implementation of sustainability aspects to different levels in decision-making (Geels and Kemp, 2012).

During these last two decades, smartness became another mainstream topic in urban development and research. And in this context, the discourse has changed as well. Initially, "smartness" was mostly equated with digitization and automation of (networked) technical infrastructures in the context of communication technologies (Caragliu et al., 2011). Smartness was additionally conceived as a development concept for highly urbanized centers with economic growth and globalized capital flows and markets. Right from the beginning, smartification was seen as large-scale technical restructuring process toward more efficient infrastructures that could only be realized by investing large amounts of money (Sadowski and Bendor, 2019; Sadowski, 2020). In consequence, the commitment of private and globalized tech companies seemed necessary as municipal budgets are very strained in many cases and technological competence for setting up new and smart infrastructures was lacking as well. But this also meant that the private-sector logic of economic competition was applied (Nam and Pardo, 2011; ZTG, 2017).

Nonetheless, a higher efficiency of infrastructures is—until today—promoted as a means to achieve more ecological sustainability. The idea is that in a fully networked system resources can be used much more efficiently (Gil-Garcia et al., 2016). Such a system can only be effective if a large part of the infrastructure is being "smartified" and if the efficiency is not being watered down by human behavior. So far, however, there is little empiric knowledge to what extent resources are actually being saved in smart neighborhoods or smart cities (Akande et al., 2019).

Such a technology-driven approach has been challenged by social activists (Stollmann et al., 2016), sustainability activists (Höfner and Frick, 2019) as well as political think tanks (WBGU, 2018). This is due to the realization that what is technically feasible does not always contribute to solving social issues. These activists rather argue that smart technologies should bring actual societal benefit and that solutions must be developed with or by civil society and that aspects of security and privacy and as well as of power distribution and governance have not been addressed sufficiently yet (Stollmann et al., 2016; Ismagilova et al., 2020).

Similar to sustainable urban development, "smartness" has been applied to cities all over the world. And the number of cities is growing which explicitly try to relate smartness and sustainability (Akande et al., 2019; Ahvenniemi and Huovila, 2021). Such more recent approaches share the idea that smart technologies should support sustainable development, that "digitalization can be put at the service of global sustainability" (WBGU, 2018, p. 1; see also Caputo et al., 2018)—not the other way around. Some of these cities do not only aim for ecological sustainability but also for economic and social sustainability.

Vienna, a pioneer in terms of a socially embedded definition of urban smartness, "denotes a city [a smart city] in which information and communication technologies as well as resource-saving technologies are systematically used in order to pave the way to a post-fossil society, to reduce the consumption of resources decrease, to permanently increase the quality of life of the citizens and the competitiveness of the local economy,—thus to improve the future viability of the city" (https://www.wienerstadtwerke.at/smart-city; Loew and Rohde, 2015). Another example for an integrated understanding is Amsterdam where different stakeholder groups are explicitly integrated in urban development processes (https://amsterdamsmartcity.com/).

First experiences indicated conceptual and practical problems in implementing smartness and sustainability in cities (Evans et al., 2019). These originate in the difficulty to reconcile scales, scopes and objectives of both concepts. Case studies indicate that different cities develop different definitions of and approaches to becoming smart and sustainable (Lara et al., 2016; Stollmann et al., 2016).

Similar to changed discourses on sustainable development, more recent strategies for urban smartness emphasize the need to, first, strengthen participatory and co-creative approaches in order to develop more socially-inclusive, democratic and need-based solutions (ZTG, 2017; Aurigi and Odendaal, 2021). Second, the importance of learning and different forms of knowledge was already an integral part of some early smart city concepts, for example in "Knowledge Cities" in Australia or South Africa (Yigitcanlar et al., 2008). While variety in definitions and approaches seems a feasible way of dealing with the complexity of implementation processes, successful new approaches will still need to integrate different sectors, different responsibilities, different levels of governance and different objectives. But, third, research on governance of smart cities is still an emerging topic as it focuses mostly in a very theoretical level on the relations of ICT and humanity resp. societies (Jiang et al., 2020).

Similar developments of both concepts have been described above, but there are also opposed developments to be observed. In the Smart City context, very large, technology-driven solutions were initially developed. Gradually, these approaches are being supplemented by smaller-scale, site-specific approaches. The opposite development can be observed in the context of sustainable development: Here, arguments are made that small-scale approaches are usually not enough to achieve noticeable

sustainability effects—rather radical, large-scale and integrated solutions are being demanded (Van Den Bergh et al., 2011; Markard et al., 2012).

It should also be noted that aspects of smartness have so far only played a subordinate role in the context of sustainable development (Höfner and Frick, 2019) and that sustainability is just one aspect in smart cities (Yigitcanlar et al., 2019). Related discussions are still evolving while practical experiments tackling both smartness and sustainability are scarce yet. In consequence, research into any positive or negative relations and effects of both concepts is still in its early stages.

THE CASE OF SUSTAINABLE AND SMART URBAN MOBILITY

Urban mobility is one of the major sectors of application for sustainability and smartness. In the following, characteristics of both concepts will be framed in this context. Any transformation of existing urban mobility systems can be considered a challenge as the idea of a privately-owned car is deeply rooted in many of our cultures and mindsets. For decades, owning a car promised independence, flexibility, comfort on the individual level, and the manufacturing of cars promises economic stability on the societal level (Canzler, 2000; Jeekel, 2016). The hegemony of such thinking manifested in urban layouts as well as in our daily behaviors—but there are indications for change (Canzler et al., 2018).

In consequence, a transformation toward more sustainable mobility can only be achieved if profound changes take place: On the individual level, this implies a reduction of the need and wish to travel for work or leisure (fewer and shorter trips) (Banister, 2008; Foltýnová et al., 2020; Loy et al., 2021)—a substantial behavior change in short. On the societal level this means different political, legal and economic frameworks (Schipper et al., 2020) including more emphasis on other modes of mobility such as walking and biking, on health and quality of life (Larranaga et al., 2019; Blečić et al., 2020; Del Aguila, 2021). Both approaches, though very much needed, are complex and long-term processes to deal with (Cascetta et al., 2007). In order to be successful they rely increasingly on the involvement of large parts of society (Kiba-Janiak and Witkowski, 2019; Fernandez-Heredia and Fernandez-Sanchez, 2020), on collective discussion and participation (Lindenau and Böhler-Baedeker, 2014). So far, such approaches have been implemented both on the neighborhood and city levels with different scopes and goals (Mozos-Blanco et al., 2018; Loorbach et al., 2021). Similar to discussions on sustainable urban development in general, it has been acknowledged that a transformation of the mobility system will need different approaches and different paths in different locations if successful (Foltýnová et al., 2020).

A more feasible solution toward more sustainability in the mobility sector—and this is a third approach—seems to reduce emissions by increasing the efficiency of cars. This clearly is a technology-driven approach, substituting privately owned petrol-powered cars either by other privately-owned drive technologies or by other means of transport such as all forms of shared mobility. This approach relies heavily on business ideas of large private car manufacturers, and a growing number of start-ups (Bellini et al., 2019). These still tend to produce supply-led, and infrastructure-centered isolated solutions (Blechschmidt et al., 2015; Brunnengräber, 2020) where people are being conceived as users. The concept of "Mobility as a Service/MaaS", aiming at improving user experiences, being one such recent trend (Utriainen and Pöllänen, 2018). Unfortunately, it is still difficult to quantify positive or negative environmental effects, even more to assess indirect environmental impacts or social, respectively, societal impacts (Pape and Lauwers, 2015). Nevertheless, there are systematic scientific approaches for comprehensive sustainability assessments and recommendations for specific indicators in the context of urban mobility (Gerlach et al., 2015; Jeekel, 2017).

But there are approaches to frame urban mobility differently—with a more comprehensive understanding of the relations of mobility to our daily lives. Discussions on health effects, individual safety as well as quality of life and public space support the idea of more socially inclusive and sustainable forms of mobility (Jeekel, 2017; Evans et al., 2019; Ahvenniemi and Huovila, 2021).

The concept of smart mobility initially emphasized networked infrastructures as a means to enhance energy efficiency and to reduce emissions (Wolter, 2012; Ilarri et al., 2015). In consequence, developing more efficient forms of fuel and engines became a major objective along with the idea of shared vehicles and automated driving (Brunnengräber, 2020; Butler et al., 2020). Especially the latter is an expression of the idea of unrestricted mobility where vehicle's efficiency is not negatively influenced by the human factor (Xing et al., 2021). Such an approach is close to argumentative patterns for more ecological sustainability through new technologies.

Maybe more than in any other sector, the discourse of smartness in the mobility sector has been equated or rather confused not only with ecological sustainability but with sustainability in general (Jeekel, 2017). In consequence, research on effects of smart mobility focuses on assessing the effects on the environment. Still in its early stages and consequently lacking standards, recent research applies different parameters and indicators (Nijland and van Meerkerk, 2017; Arbeláez Vélez and Plepys, 2021) which makes it rather difficult to compare.

Economic and in particular social sustainability are topics that need still to be explored in the context of smart mobility (Pape and Lauwers, 2015; Jeekel, 2017). Knowledge about movements, capacities, flows, user behavior is in any context considered important. But a technology-driven approach tends to conceive knowledge as automated data, collected via sensors, apps and other digital platforms (Van Oers et al., 2020). While this may generate issues with privacy in urban space, these data are comparatively easy to collect. But it needs to be mentioned that data gained in such a way describes rather existing mobility flows than deals with actual demands.

Recently, more comprehensive ideas of smart mobility have been developed, relating to a more comprehensive understanding of sustainability or to the three pillars of sustainability (Uteng et al., 2019). In consequence, and similar to implementing

sustainability or smartness in general, practical experiences with smart mobility resulted in a diversification of definitions and approaches such as reducing the number of individually possessed cars, increasing safety in urban space, promoting more sustainable lifestyles and to develop hybrid (digital and non-digital) solutions for a variety of user groups (Benevolo et al., 2016). In this context, a turn to more demand-oriented, behavior-based and sometimes co-created solutions can be noticed (Blechschmidt et al., 2015; Benevolo et al., 2016).

Transforming urban mobility systems implies dealing with sustainability and smartness at the same time. However, more comprehensive approaches have rarely been developed yet (Frantzeskaki et al., 2017). But there are some exceptions: Again, the importance of different forms of knowledge is being emphasized (Hegyi et al., 2019; Vecchio and Tricarico, 2019). In addition, there is comparatively little knowledge on the governance of such comprehensive processes (Docherty et al., 2018; Kronsell and Mukhtar-Landgren, 2020; Paiva et al., 2021) where many developments happen at the same time, are co-evolving but not co-ordinated (Jeekel, 2017).

Introducing Sustainable and Smart Urban Mobility to Berlin

Since 2016, the transdisciplinary project NEUE MOBILITÄT BERLIN (http://neue-mobilitaet.berlin/) aims at collectively developing, exploring and testing adequate strategies for more sustainable and smarter mobility in Berlin/Germany. The core team consists of the District Office Charlottenburg-Wilmersdorf as political and administrative institution, the Center for Technology and Society/TU Berlin as scientific partner for qualitative research and policy development, the Competence Center for Urban Mobility BMW Group as a mobility provider, the innovation agency eMo of the city of Berlin as a state agency and, most importantly, insel-projekt Berlin, a local organization for sustainable development in that part of Berlin. This team developed different formats over time to promote sustainable mobility locally, together with other organizations and stakeholders.

Early in the project, the team had to learn that mobility is indeed a highly contested and emotionalized topic making it difficult to start conversations on the topic. In addition, it became obvious that individual mobility and mobility behavior are topics which are rarely reflected in (Berlin) society. From this, two consequences can be drawn: First, in order to develop a truly different, effective and successful approach to sustainable and smart mobility, intensive (one-to-one) communication with individuals and stakeholder groups is necessary. Second, in order to deal with non-information, misinformation, increasing awareness, mutual learning, playful testing etc. are crucial (Wendorf and Schröder, 2018; Schröder and Wendorf, 2019). In consequence, the team developed a variety of formats for information, communication, and testing with and for different groups of participants—from personal discussions in open space, to large public forums, to the temporary conversion of street space. Documentations of the formats can be found on the project website.

One format developed during the project was the "Sommerflotte/Summer Fleet" campaign in 2018 and 2019, renamed "Deine Flotte/Your Fleet" in 2020 and 2021. The latter is—at the time of writing this article—still ongoing and therefore not being referred to here. Relating to our initial findings summarized in Section 2.1, the main objective of the campaigns was to facilitate individual testing of alternative forms of sustainable and smart mobility in order to allow for more informed decisions on individual mobility. Accompanying research focussed on individual demands for everyday mobility. During the campaigns, voluntary participants would not use their private car for 4 weeks, but experience different forms of smart and sustainable mobility. In order to support this approach, digital vouchers for some fifteen participating mobility providers during each campaign were handed over to the participants. Vouchers included conventional (non-electric) bike sharing, stationary and free-floating car sharing (both electric and non-electric), e-moped sharing, e-scooter sharing as well as ride sharing (in 2019) and cargo bikes (in 2020).

Many people we talked to over the years were curious about using mobility alternatives, but for various reasons hadn't done so yet. Altogether, the campaigns drew 111 participants so far: 63 male, 47 female and one without specification. Eighty-eight of them, a considerable number, had a university degree and their average age was slightly below 47 years.

Before and after their participation, the participants were interviewed online *via* questionnaires. Each of the questionnaires included closed, multiple choice and open questions. In accordance with the overall objective mentioned above, questions ranged from the original reasons why participants acquired a car, to everyday mobility routines and general preferences, to their expectations for taking part in the campaign, their specific experiences while using the mobility formats offered as well as their individual consequences from taking part in this campaign (NMB, 2020).

Results and Findings From the Campaigns

When asked why they participated in the campaigns, two major reasons became apparent: Just under half of the participants was curious about testing new technologies, a slightly smaller number indicated that their environmental awareness made them reflect about changing their lifestyles and the campaign was a welcomed offer to test possible consequences of abolishing their car. Even before the campaign, the majority of participants had been aware of the existence of alternatives. But only a very small part had already tested them as they felt that they hadn't had any opportunity yet to do so (NMB, 2020).

Despite using a large variety of media for advertising the campaign—from classical local and national newspapers to social media, radio trailers and radio partnerships, large-scale posters in metro stations and small format posters in shops, the campaigns drew a very specific group of people: Besides being middle-aged and highly educated, the participants considered themselves open to experiments in general and possessed a certain digital literacy as they knew how to use a smartphone, and how to sign into digital platforms (NMB, 2020).

After taking part, the participants were "very" to "quite" satisfied with the mobility alternatives offered. Initial fears that more time and organization would be needed without their own car did not prove right in almost all cases. In other words, everyone managed their daily mobility throughout the 4 weeks—except for, and this is significant, three use cases. These were: the transport of family members, the transport of large or heavy goods, and trips beyond the business areas of the mobility providers (Schröder and Wendorf, 2019).

Another challenge for the participants—regardless of their age—was to fully understand the handling as well as the potentials of different forms of mobility, for example: If I manage to use one car from a specific mobility provider, why are all other cars different? Can I leave the business area with my car/moped? How can I combine different forms of mobility to suit my personal needs? The large variety of vehicles and business models seemed to overwhelm some participants as they would have had to acquire a lot of practical knowledge within the rather short timeframe of 4 weeks in order to test all possibilities offered. In order to close these knowledge gaps, the project team developed different forms of practical assistance over the years such as preparatory meetings, individual trainings and a detailed manual with information on how to use each vehicle and app.

The most popular forms of alternative mobility during the campaigns were people's private bikes, followed by public transport and free-floating carsharing. Interestingly, these preferences did not change in 2020 during the first year of COVID-19, in contrast to findings from other research (AGORA Verkehrswende, 2020). To sum up, the two most popular modes of mobility (private bikes and public transport) during the campaigns were rather traditional ones, not exactly those associated with smartness in the literature. In contrast, the least popular modes of mobility were stationary carsharing and cargo bikes. Stationary carsharing—in contrast to free floating carsharing—had been experienced as rather impractical as the participants felt that the stations were too far from where they needed them. Cargo bikes just seemed not necessary during their participation.

Before the campaign, concerns were expressed that participants' daily life and convenience would be affected in a negative way. Using alternative modes of transport was considered more time-consuming and difficult to organize, especially for spontaneous activities or activities with family members. These concerns proved too strong as only a third of the participants reported major challenges to their comfort zone. This low number of reported challenges could either mean that these participants were reluctant to try really challenging things or that the challenges were considered insignificant. But with the other two thirds, two different strategies of coping could be observed: roughly half of those who experienced challenges to their lifestyle before the campaigns took it as a motivation to find ways to cope. The other half experienced the challenges as a reinstatement of their initial assumptions and decided that alternative mobility does not suit their needs to a sufficient degree. Thus, when we asked whether the participation in the 4-week campaign had changed anything in their mind toward the possession and use of a private car, everyone stated that they now know that it is possible to move through the city without their own car. Two thirds were positive that they would use mobility alternatives more often in the future and egally two thirds stated that they are still thinking of abolishing their car. A good quarter of the participants made the decision, and did indeed abolish their cars for good within several weeks of the end of the campaigns (NMB, 2020). To sum up, taking part in the campaigns helped people to change their mobility lifestyles toward more sustainability. New technologies can certainly applied to support this cause, but several practical challenges still need to be overcome.

DISCUSSION AND CONCLUSION

The campaigns and the accompanying research provided insights into systemic and practical challenges to introducing sustainable and smart urban mobility. It can already be stated that relations between (new) technologies, individual mobility behavior and sustainability awareness are complex. In general, the participants were positively surprised by the number and quality of the existing inner-city mobility alternatives in Berlin, both public and private transport. But it became obvious that the supply of vehicles is spatially fragmented: Trips beyond the inner city, beyond S-Bahn-Ring, were more difficult to arrange as the business areas of most providers do not expand much beyond this central area yet. Similarly, it was much more difficult for participants living in peripheral areas to access alternative forms of mobility, even more so any form of shared mobility. In addition, business areas differ in shape and size, based on the business models of each provider. Both aspects result in the fact that it is difficult to understand which vehicle or mobility provider can be used in which area. This may have some negative impact on people's willingness to use alternative mobility.

Adding to the confusion which vehicle to use in which area was the rather poor state of internet connections in peripheral areas. Compared to other countries, internet and mobile connectivity in Germany are rather low (https://www.mobileconnectivityindex.com/) and patchy (https://www.breitband-monitor.de/funkloch/karte). The further one travels from the inner city, the more likely it is that one cannot un/lock a shared vehicle via app. This clearly demonstrates the interrelations of sustainability through smartness: new shared forms of mobility depend on functioning smart infrastructures. Thus, smart mobility remains—in its existing form—an approach for dense, urban centers.

New (shared) forms of mobility equally depend on the digital literacy of any user, as a precondition for (more) sustainable behavior. While such a technology-focussed understanding of sustainable mobility may be questioned in general, another technological aspect adds to the complexity: So far, there is not one platform to access all mobility services but each provider developed their own app which everyone is obliged to use (no single sign-on option). In consequence, participants had to sign

into each app separately. This resulted in some participants only using a small variety of services and only those services they found easy to handle. Last but not least, in order to use the mobility apps, google accounts were needed in most cases. This raised some issues with people concerned about their digital privacy. On the contrary, walking, private bikes and—depending on the respective business model—public transport and cargo bikes are forms of mobility that can still be experienced without going digital.

As mentioned before, the campaigns reached only a specific type of people. An explanation could be that such a technology-driven approach to alternative mobility can be introduced more easily to people who are open to or have some experience with new technologies, who are at the same time environmentally aware and have, in addition, already reflected their mobility behavior to a certain degree. During the campaigns, each participant gained knowledge on how to (not) use different forms of alternative mobility and what their actual individual mobility demands are. During the testing, initial worries that the handling of the vehicles and applications would be difficult disappeared in most cases. And their experiences clearly supported them in making informed decisions about abandoning their own car for good. This confirms the pre-campaign findings that information and opportunities for testing are important facilitating aspects for individual involvement in a transformation toward a more sustainable and smart mobility system. Nonetheless, the campaigns as well as the provision of information were quite demanding and time-consuming for the team.

But even in this rather homogenous group of participants, three major use cases could be identified where people felt that a private car is needed. These were—as mentioned above—transport of family members, transport of large or heavy goods, and trips beyond the business areas of the mobility providers for leisure. Maybe not surprisingly, these were also the main three reasons why participants were reluctant to abandon their private cars for good after taking part. In consequence, a reduction of privately owned cars will only be achieved if feasible and adequate solutions for these use cases can be developed—for example, leisure activities such as jogging, allotment gardening or horse riding usually require to carry bulky or heavier goods.

As mentioned above, a very specific type of people had been attracted by the campaigns. Population groups that could not be reached were for example: families with two or more children, young people, people with physical or health restrictions, and non-German speaking citizens. In consequence, we still know little about mobility demands of those groups or how they could be reached. And it certainly raises the question how urban mobility as such could be more inclusive.

The focus of the campaigns described was clearly technology-driven as they offered access to new technologies for testing. Following the initial question how and to what extent smart technologies can support sustainable development, there are two significant aspects to be observed from the research results. For one, several very practical technical issues complicate a transition from a society with individually owned cars to a different, more sustainable and smarter urban mobility system, most of all connectivity and the knowledge of how to handle vehicles. From the findings, it can be concluded that existing business models do only provide singular solutions for some of the practical mobility challenges in daily life. Another observation is that existing supply-centered business models are not sufficiently diversified yet while their actual contributions to ecological sustainability are still unclear.

For another, and on a much broader scale, the results challenge technology-driven "smart" approaches to urban mobility. It should be investigated how and to which extent specific smart solutions facilitate a more sustainable urban mobility system. As of today, the landscape of sustainable and smart mobility—and their assessment—seems still rather fragmented. A comprehensive sustainable and smart urban mobility system will need more integration and coordination: This goes not only for technological developments but also for the development of feasible but comprehensive governance structures to overcome fragmented responsibilities, isolated solutions and path dependencies (Schwedes and Kollosche, 2016; Docherty et al., 2018; Uteng et al., 2019).

In consequence, a truly different and comprehensive approach to urban mobility is needed, including a complete reconsideration of the architecture of urban mobility systems. This means actively relating traditional and clearly sustainable modes of mobility (walking, using your private bike, public transport) to more recent approaches. This also asks to develop different legal and economic frameworks that allow for better integration. And this includes developing suitable governance structures for cities and municipalities with notoriously lacking resources (Dameri and Benevolo, 2016; Docherty et al., 2018). In this context, the importance of different forms of knowledge could be confirmed (Kronsell and Mukhtar-Landgren, 2020; Mukhtar-Landgren and Paulsson, 2021): During the campaigns, participants were enabled to take informed decisions and consequently change their lifestyles toward more sustainability. At the same time, it became obvious that such singular experiments only have limited effects as the number of participants is limited and funding for qualitative research in comprehensive, inclusive urban mobility is difficult to find. In any case, it would be very helpful to bring together experiences and research on alternative mobility in a more systematic way.

Today, we are certainly in a transitional phase of the mobility system. And of course, there are many questions still unanswered. New forms of urban mobility are just one way to combine sustainable and smart aspects. Motivations to use them seem diverse and their attractiveness is not necessarily related to a more sustainable lifestyle. Some practical challenges to introducing sustainable and smart mobility have been described above. But in order to assess their factual positive and negative effects, more information and research is needed—on efficiency, reduction of emissions as well as on mobility demands, on mobility behavior, and on governance. On a more abstract level this would also mean to discuss contributions of such forms of mobility to health, safety, and quality of life. Or to discuss the sustainability of different business models, the energy demand of smart applications and data bases or the increased use of rare metals for e-mobility. For example, from a sustainability viewpoint, one could even argue that truly sustainable, demand-oriented business models should provide more vehicles in peripheral areas.

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The author confirms being the sole contributor of this work and has approved it for publication.

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REFERENCES

AGORA Verkehrswende (2020). *Ein anderer Stadtverkehr ist möglich. Neue Chancen für eine krisenfeste und -klimagerechte Mobilität*. Berlin. Available online at: https://www.agora-verkehrswende.de/veroeffentlichungen/ein-anderer-stadtverkehr-ist-moeglich/ (accessed September 14, 2021).

Ahvenniemi, H., and Huovila, A. (2021). How do cities promote urban sustainability and smartness? An evaluation of the city strategies of six largest Finnish cities. *Environ. Dev. Sustain.* 23, 4174–4200. doi: 10.1007/s10668-020-00765-3

Akande, A., Cabral, P., Gomes, P., and Casteleyn, S. (2019). The Lisbon ranking for smart sustainable cities in Europe. *Sustain. Cities Soc.* 44, 475–487. doi: 10.1016/j.scs.2018.10.009

Alber, G. (2013). "Die sozialen Dimensionen von Klimawandel und Klimapolitik," in *Genossenschaften und Klimaschutz: Akteure für zukunftsfähige, solidarische Städte*, eds C. Schröder, and H. Walk. Vol. 41 (Springer-Verlag), 109–134.

Arbeláez Vélez, A. M., and Plepys, A. (2021). Car sharing as a strategy to address GHG emissions in the transport system: Evaluation of effects of car sharing in Amsterdam. *Sustainability* 13, 2418. doi: 10.3390/su1304 2418

Aurigi, A., and Odendaal, N. (2021). From "Smart in the Box" to "Smart in the City": rethinking the socially sustainable smart city in context. *J. Urban Technol.* 28, 55–70. doi: 10.1080/10630732.2019.1704203

Banister, D. (2008). The sustainable mobility paradigm. *Transport Policy* 15, 73–80. doi: 10.1016/j.tranpol.2007.10.005

Beatley, T. (2014). "Planning for sustainability in european cities: a review of practice in leading cities," in *Sustainable Urban Development Reader* (Routledge), 440–449.

Bellini, F., Dulskaia, I., Savastano, M., and D'Ascenzo, F. (2019). Business models innovation for sustainable urban mobility in small and medium-sized European cities. *Manage. Market.* 14, 266–277. doi: 10.2478/mmcks-2019-0019

Benevolo, C., Dameri, R. P., and D'Auria, B. (2016). *Smart Mobility in Smart City. Empowering Organizations*. Cham: Springer 13–28. doi: 10.1007/978-3-319-23784-8_2

Blechschmidt, A., Lanzendorf, M., and Wilde, M. (2015). Integrierte Stadtentwicklung und die Gestaltung nachhaltiger Mobilität – Zum Stand der Planungspraxis am Beispiel der Stadt Leipzig. *Raumforschung und Raumordnung* 73, 423–437. doi: 10.1007/s,13147-015-0372-5

Blečić, I., Congiu, T., Fancello, G., and Trunfio, G. A. (2020). Planning and design support tools for walkability: a guide for urban analysts. *Sustainability* 12, 4405. doi: 10.3390/su12114405

BMUB (2007). *Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit. Leipzig Charta zur nachhaltigen europäischen Stadt*. Berlin. Available online at: https://www.bmu.de/fileadmin/Daten_BMU/Download_PDF/Nationale_Stadtentwicklung/leipzig_charta_de_bf.pdf (accessed March 27, 2021).

Brunnengräber, A. (2020). Zum E-Auto gezwungen. *Ökologisches Wirtschaften-Fachzeitschrift* 2, 30–33. doi: 10.14512/OEW350230

Bulkeley, H., and Betsill, M. (2005). Rethinking sustainable cities: multilevel governance and the'urban'politics of climate change. *Environ. Polit.* 14, 42–63. doi: 10.1080/0964401042000310178

Butler, L., Yigitcanlar, T., and Paz, A. (2020). Smart urban mobility innovations: a comprehensive review and evaluation. *IEEE Access* 8, 196034–196049. doi: 10.1109/ACCESS.2020.3034596

Canzler, W. (2000). *Das Auto im Kopf und vor der Haustür: Zur Wechselbeziehung von Individualisierung und Autonutzung*. Soziale Welt, 191–207.

Canzler, W., Knie, A., Ruhrort, L., and Scherf, C. (2018). "Erloschene Liebe? Das Auto in der Verkehrswende," in *Erloschene Liebe? Das Auto in der Verkehrswende*. transcript-Verlag.

Caputo, F., Buhnova, B., and Walletzk,ý, L. (2018). Investigating the role of smartness for sustainability: insights from the Smart Grid domain. *Sustain. Sci.* 13, 1299–1309. doi: 10.1007/s11625-018-0555-4

Caragliu, A., Del Bo, C., and Nijkamp, P. (2011). Smart cities in Europe. *J. Urban Technol.* 18, 65–82. doi: 10.1080/10630732.2011.601117

Cascetta, E., Pagliara, F., and Papola, A. (2007). Governance of urban mobility: complex systems and integrated policies. *Adv. Complex Syst.* 10, 339–354. doi: 10.1142/S0219525907001392

Clune, W. H., and Zehnder, A. J. (2018). The three pillars of sustainability framework: approaches for laws and governance. *J. Environ. Protect.* 9, 211–240. doi: 10.4236/jep.2018.93015

Dameri, R. P., and Benevolo, C. (2016). Governing smart cities: an empirical analysis. *Soc. Sci. Comput. Rev.* 34, 693–707. doi: 10.1177/0894439315611093

Del Aguila, M. (2021). Neighbourhood environment walkability and the independence of older people: a comment on the 30-year plan for greater Adelaide. *Austr. Plan.* 57, 1–5. doi: 10.1080/07293682.2021.2017993

Docherty, I., Marsden, G., and Anable, J. (2018). The governance of smart mobility. *Trans. Res. Part A Policy Pract.* 115, 114–125. doi: 10.1016/j.tra.2017.09.012

Elmqvist, T., Andersson, E., Frantzeskaki, N., McPhearson, T., Olsson, P., Gaffney, O., et al. (2019). Sustainability and resilience for transformation in the urban century. *Nat. Sustain.* 2, 267–273. doi: 10.1038/s41893-019-0250-1

EU (2020). *The New Leipzig Charter. The Transformative Power of Cities for the Common Good*; EU2020.de. European Commission: Brussels. Available online at: https://ec.europa.eu/regional_policy/en/newsroom/news/2020/12/12-08-2020-new-leipzig-charter-the-transformative-power-of-cities-for-the-common-good (accessed March 19, 2022).

Evans, J., Karvonen, A., Luque-Ayala, A., Martin, C., McCormick, K., Raven, R., et al. (2019). Smart and sustainable cities? Pipedreams, practicalities and possibilities. *Local Environ.* 24, 557–564. doi: 10.1080/13549839.2019.16 24701

Fernandez-Heredia, A., and Fernandez-Sanchez, G. (2020). Processes of civic participation in the implementation of sustainable urban mobility systems. *Case Stud. Transport Policy* 8, 471–483. doi: 10.1016/j.cstp.2019.10.011

Foltýnová, H. B., Vejchodská, E., Rybová, K., and Květon, V. (2020). Sustainable urban mobility: one definition, different stakeholders' opinions. *Trans. Res. Part D Transport Environ.* 87, 102465. doi: 10.1016/j.trd.2020.102465

Frantzeskaki, N., Broto, V. C., Coenen, L., and Loorbach, D. (2017). *Urban Sustainability Transitions*. Vol. 5. Abingdon: Taylor & Francis.

Geels, F. W., and Kemp, R. (2012). "The multi-level perspective as a new perspective for studying sociotechnical transitions," in *Automobility in Transition? A Socio-Technical Analysis of Sustainable Transport*, eds F. W. Geels, R. Kemp, G. Dudley, G. Lyons (New York: Routledge), 49–79.

Gerlach, J., Hübner, S., Becker, T., and Becker, U. (2015). *Entwicklung von Indikatoren im Bereich Mobilität für die Nationale Nachhaltigkeitsstrategie*. Umweltforschungsplan des Bundesministeriums für Umwelt, Naturschutz, Bau und Reaktorsicherheit Forschungskennzahl 3713 12 102 UBA-Texte 12/2015.

Gil-Garcia, J. R., Pardo, T. A., and Nam, T. (2016). *A Comprehensive View of the 21st Century City: Smartness as Technologies and Innovation in Urban Contexts*. Smarter as the new urban agenda. Cham: Springer, 1–19.

Glass, L. M., and Newig, J. (2019). Governance for achieving the sustainable development goals: how important are participation, policy coherence, reflexivity, adaptation and democratic institutions? *Earth Syst. Govern.* 2, 100031. doi: 10.1016/j.esg.2019.100031

Hegyi, F. B., Morgen, H., and Vendel, M. (2019). *Urban Mobility in Transformation: Demands on Education to Close the Predicted Knowledge Gap*. Transforming Urban Mobility 114. Available online at: https://www.dtu.dk/english/-/media/DTUdk/Forskning/Publikationer/dtu-2019-international-energy-report-transforming-urban-mobility.ashx?la=da&hash=2C4A459BF752145919818446AB604BDE0CE4A5ED#page=57 (accessed March 21, 2022).

Höfner, A., and Frick, V. (2019). *Was Bits und Bäume verbindet*. Digitalisierung nachhaltig gestalten. München: Oekom.

Ilarri, S., Stojanovic, D., and Ray, C. (2015). Semantic management of moving objects: a vision towards smart mobility. *Expert Syst. Appl.* 42, 1418–1435. doi: 10.1016/j.eswa.2014.08.057

Ismagilova, E., Hughes, L., Rana, N. P., and Dwivedi, Y. K. (2020). Security, privacy and risks within smart cities: Literature review and development of a smart city interaction framework. *Inform. Syst. Front.* 1–22. doi: 10.1007/s10796-020-10044-1

Jeekel, H. (2016). *The Car-Dependent Society: A European Perspective*. London: Routledge.

Jeekel, H. (2017). Social sustainability and smart mobility. Exploring the relationship. *Trans. Res. Proc.* 25, 4296–4310. doi: 10.1016/j.trpro.2017.05.254

Jiang, H., Geertman, S., and Witte, P. (2020). Smart urban governance: an alternative to technocratic "smartness". *GeoJournal* 87, 1–17. doi: 10.1007/s10708-020-10326-w

Kiba-Janiak, M., and Witkowski, J. (2019). Sustainable urban mobility plans: how do they work?. *Sustainability* 11, 4605. doi: 10.3390/su11174605

Krellenberg, K., Koch, F., and Kabisch, S. (2016). Urban sustainability transformations in lights of resource efficiency and resilient city concepts. *Curr. Opin. Environ. Sustain.* 22, 51–56.

Kronsell, A., and Mukhtar-Landgren, D. (2020). "Experimental governance of smart mobility: some normative implications," in Shaping Smart Mobility Futures: Governance and Policy Instruments in Times of Sustainability Transitions, eds A. Paulsson, and C.H. Sørensen (Bingley: Emerald Publishing Limited), 119–135. doi: 10.1108/978-1-83982-650-420201007

Lara, A. P., Da Costa, E. M., Furlani, T. Z., and Yigitcanlar, T. (2016). Smartness that matters: towards a comprehensive and human-centred characterisation of smart cities. *J. Open Innovat. Technol. Market Complex.* 2, 8. doi: 10.1186/s40852-016-0034-z

Larranaga, A. M., Arellana, J., Rizzi, L. I., Strambi, O., and Cybis, H. B. B. (2019). Using best–worst scaling to identify barriers to walkability: a study of Porto Alegre, Brazil. *Transportation* 46, 2347–2379. doi: 10.1007/s11116-018-9944-x

Lindenau, M., and Böhler-Baedeker, S. (2014). Citizen and stakeholder involvement: a precondition for sustainable urban mobility. *Trans. Res. Proc.* 4, 347–360. doi: 10.1016/j.trpro.2014.11.026

Loew, T., and Rohde, F. (2015). *Die Wiener Smart City Definition–Betrachtungen zu deren Verwendung*. Berlin. Available online at: https://www.4sustainability.de/wp-content/uploads/2021/06/Loew-Rohde_Wiener-Smart_City-Definition_Betrachtungen-zur-Verwendung2015.pdf (accessed May 04, 2018).

Loorbach, D., Schwanen, T., Doody, B. J., Arnfalk, P., Langeland, O., and Farstad, E. (2021). Transition governance for just, sustainable urban mobility: an experimental approach from Rotterdam, the Netherlands. *J. Urban Mobil.* 1, 100009. doi: 10.1016/j.urbmob.2021.100009

Loy, L. S., Tröger, J., Prior, P., and Reese, G. (2021). Global citizens–global jet setters? The relation between global identity, sufficiency orientation, travelling, and a socio-ecological transformation of the mobility system. *Front. Psychol.* 12, 622842. doi: 10.3389/fpsyg.2021.622842

Markard, J., Raven, R., and Truffer, B. (2012). Sustainability transitions: an emerging field of research and its prospects. *Res. Policy* 41, 955–967. doi: 10.1016/j.respol.2012.02.013

Mozos-Blanco, M. Á., Pozo-Menéndez, E., Arce-Ruiz, R., and Baucells-Aletà, N. (2018). The way to sustainable mobility. A comparative analysis of sustainable mobility plans in Spain. *Trans. Policy* 72, 45–54. doi: 10.1016/j.tranpol.2018.07.001

Mukhtar-Landgren, D., and Paulsson, A. (2021). Governing smart mobility: policy instrumentation, technological utopianism, and the administrative quest for knowledge. *Adm. Theory Praxis* 43, 135–153. doi: 10.1080/10841806.2020.1782111

Nam, T., and Pardo, T. A. (2011). "Conceptualizing smart city with dimensions of technology, people, and institutions," in *Proceedings of the 12th Annual International Digital Government Research Conference: Digital Government Innovation in Challenging Times* (ACM).

Nijland, H., and van Meerkerk, J. (2017). Mobility and environmental impacts of car sharing in the Netherlands. *Environ. Innovat. Soc. Trans.* 23, 84–91. doi: 10.1016/j.eist.2017.02.001

NMB (2020). "Mobilität ohne privates Auto erleben. Ergebnisse der Berliner SOMMERFLOTTE," in *Thomas Stein, Uta Bauer (Hrsg.): Bürgerinnen und Bürger an der Verkehrswende beteiligen. Erkenntnisse, Erfahrungen und Diskussionsstand des Städtenetzwerktreffens aus dem laufenden BMU-Forschungsprojekt City2Share und kommunaler Umsetzungspraxis*. 3. City2Share-Diskussionspapier, Berlin : Neue Mobilität Berlin, 30–33.

Ott, K. (2009). Leitlinien einer starken Nachhaltigkeit. Ein Vorschlag zur Einbettung des Drei-Säulen-Modells. *Gaia* 18, 25–28. doi: 10.14512/gaia.18.1.9

Paiva, S., Ahad, M. A., Tripathi, G., Feroz, N., and Casalino, G. (2021). Enabling technologies for urban smart mobility: Recent trends, opportunities and challenges. *Sensors* 21, 2143. doi: 10.3390/s21062143

Pape, E., and Lauwers, D. (2015). "Smart mobility: opportunity or threat to innovate places and cities?," in *Proceedings Real Corp*, 544p.

Sadowski, J. (2020). Who owns the future city? Phases of technological urbanism and shifts in sovereignty. *Urban Stud.* 58, 0042098020913427. doi: 10.1177/0042098020913427

Sadowski, J., and Bendor, R. (2019). Selling smartness: Corporate narratives and the smart city as a sociotechnical imaginary. *Sci. Technol. Hum. Values* 44, 540–563. doi: 10.1177/0162243918806061

Schipper, F., Emanuel, M., and Oldenziel, R. (2020). Sustainable urban mobility in the present, past, and future. *Technol. Cult.* 61, 307–317. doi: 10.1353/tech.2020.0004

Schröder, C., and Wendorf, G. (2019). "Smart mobility: technologies and daily routines," in *Is this the real world? Proceedings of REAL CORP 2019, 24th International Conference on Urban Development, Regional Planning and Information Society*, 679–684.

Schwedes, O., and Kollosche, I. (2016). *Mobilität im Wandel*. Transformationen und Entwicklungen im Personenverkehr. Bonn: Friedrich-Ebert-Stiftung.

Stollmann, J., Wolf, K., Brück, A., Frank, S., Million, A., Misselwitz, P., et al. (2016). "Beware of smart people! Redefining the smart city paradigm towards inclusive urbanism," in *Proceedings of the 2015 "Beware of Smart People!" symposium*. Universitätsverlag der TU Berlin.

United Nations (2016). *HABITAT III New Urban Agenda*. Available online at: http://habitat3.org/wp-content/uploads/New-Urban-Agenda-GA-Adopted-68th-Plenary-N1646655-E.pdf (accessed November 20, 2020).

Uteng, T. P., Singh, Y. J., and Hagen, O. H. (2019). "Social sustainability and transport: Making 'smart mobility' socially sustainable," in *Urban Social Sustainability* eds T. P. Uteng, Y. J. Singh, and O. H. Hagen (London: Routledge), 59–77.

Utriainen, R., and Pöllänen, M. (2018). Review on mobility as a service in scientific publications. *Res. Trans. Bus. Manage.* 27, 15–23. doi: 10.1016/j.rtbm.2018.10.005

Van Den Bergh, J. C. J. M., Truffer, B., and Kallis, G. (2011). Environmental innovation and societal transitions: introduction and overview. *Environ. Innovat. Soc. Trans.* 1, 1–23. doi: 10.1016/j.eist.2011.04.010

Van Oers, L., de Hoop, E., Jolivet, E., Marvin, S., Späth, P., and Raven, R. (2020). The politics of smart expectations: interrogating the knowledge claims of smart mobility. *Futures* 122, 102604. doi: 10.1016/j.futures.2020.102604

Vecchio, G., and Tricarico, L. (2019). May the force move you: roles and actors of information sharing devices in urban mobility. *Cities* 88, 261–268. doi: 10.1016/j.cities.2018.11.007

Walter, A. I., Helgenberger, S., Wiek, A., and Scholz, R. W. (2007). Measuring societal effects of transdisciplinary research projects: design and application of an evaluation method. *Eval. Program Plann.* 30, 325–338.

WBGU (2018). *Digitalisierung: Worüber wir jetzt reden müssen*. Berlin: Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen. Available onlin at: https://www.wbgu.de/fileadmin/

user_upload/wbgu/publikationen/factsheets/digitalisierung.pdf (accessed March 15, 2021).

Wendorf, G., and Schröder, C. (2018). "The challenging path to a redistribution of space–renegotiating urban mobility," in *REAL CORP 2018–EXPANDING CITIES–DIMINISHING SPACE. Proceedings of 23rd International Conference on Urban Planning, Regional Development and Information*, 453–459.

Wolter, S. (2012). Smart Mobility - Intelligente Vernetzung der Verkehrsangebote in Großstädten. *Zukünftige Entwicklungen in der Mobilität. Gabler Verlag* 527–548.

Xing, Y., Lv, C., Cao, D., and Hang, P. (2021). Toward human-vehicle collaboration: Review and perspectives on human-centered collaborative automated driving. *Trans. Res. Part C Emerg. Technol.* 128, 103199. doi: 10.1016/j.trc.2021.103199

Yigitcanlar, T., Han, H., and Kamruzzaman, M. (2019). Approaches, advances, and applications in the sustainable development of smart cities: a commentary from the guest editors. *Energies* 12, 4554. doi: 10.3390/en12234554

Yigitcanlar, T., Velibeyoglu, K., and Martinez-Fernandez, C. (2008). Rising knowledge cities: the role of urban knowledge precincts. *J. Know. Manage.* 12, 8–20. doi: 10.1108/13673270810902902

Zscheischler, J., Rogga, S., and Weith, T. (2014). Experiences with transdisciplinary research: sustainable land management third year status conference. *Syst. Res. Behav. Sci.* 31, 751–756.

ZTG (2017). *Smart City: Zur Bedeutung des aktuellen Diskurses für die Arbeit am Zentrum Technik und Gesellschaft*. Berlin: TU Berlin.

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