8. Policy Metrics for Coherent and Socially Inclusive Urban Transformation in Mobility and Energy

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8.1. Introduction

Rationale

Cities occupy only a small portion of the Earth's surface but are home to more than half of the world's population. Thus, these are the major contributors to global greenhouse gas emissions from energy use and highly prone to the risks and effects of climate change.[3] Accordingly, cities have an important role in the

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3. Michael Acuto, Susan Parnell, and Karen C. Seto, 'Building a global urban science,' *Nature Sustainability* 1 (January 2018): 2–4. https://doi.org/10.1038/s41893-017-0013-9; Ahmed Sodiq, et al., 'Towards modern sustainable cities: Review of sustainability principles and trends,' *Journal of Cleaner Production* 227 (August 2019): 972–1001. https://doi.org/10.1016/j.jclepro.2019.04.106; United Nations Department of Economic and Social Affairs, *World Urbanization Prospects: The 2018 Revision* (New York: United Nations, 2019). http://bitly.ws/qwTG; United Nations Industrial Development Organization, *Sustainable Cities: Hubs of Innovation, Low Carbon Industrialization and Climate Action* (Vienna: UNIDO, 2016). http://bitly.ws/qwS3 decarbonisation of society, in conformation to the Paris Agreement's aim of net-zero carbon emissions by the middle of the XXI century.[4] Particularly, this concerns carbon-intensive sectors such as transportation and energy.[5]

Mobility and energy have always been connected at the supply side (through fuels and resources), while the process of decarbonisation is likely to result in stronger links/interactions between both.[6] Urban energy use will be partly supplied through local generation of electricity from e.g., solar photovoltaics (PV) and make use of storage facilities and smart grid technology to balance irregular supply and demand.[7] Meanwhile, urban mobility will shift from motorised passenger vehicles to electric counterparts that are locally recharged. Electric vehicles (EVs) battery capacity can be used to shift demand patterns (e.g., during the night time or while charging at home) and as temporary storage facilities (i.e., batteries to even provide energy for non-driving purposes during peak-demand hours). According to some engineers, early simulations and (federally funded) experimentation, these intertwining developments are commonly recognised as an efficient solution to meet the decarbonisation and sustainability challenges[8]

4. 'The Sustainable Development Goals Report 2020,' United Nations Statistics Division, accessed April 4, 2022. https://unstats.un.org/sdgs/report/2020/

5. Daniel M. Kammen and Deborah A. Sunter, 'City-integrated renewable energy for urban sustainability,' *Science* 352, no. 6288 (May 2016): 922–28. https://doi.org/10.1126/science.aad9302

6. Weert Canzler, et al., 'From "living lab" to strategic action field: Bringing together energy, mobility, and Information Technology in Germany,' *Energy Research & Social Science* 27 (May 2017): 25–35. https://doi.org/10.1016/j.erss.2017.02.003; Gaofeng Gu and Tao Feng, 'Heterogeneous choice of home renewable energy equipment conditioning on the choice of electric vehicles,' *Renewable Energy* 154 (July 2020): 394–403. https://doi.org/10.1016/j.renene.2020.03.007; Michela Longo, Federica Foiadelli, and Wahiba Yaïci, 'Electric vehicles integrated with renewable energy sources for sustainable mobility,' in *New Trends in Electrical Vehicle Powertrains*, eds. Luis Romeral Martinez and Miguel Delgado Prieto, 203–23 (London: IntechOpen, 2019). https://doi.org/10.5772/intechopen.76788; Massimiliano Manfren, Paola Caputo, and Gaia Costa, 'Paradigm shift in urban energy systems through distributed generation: Methods and models,' *Applied Energy* 88, no. 4 (April 2011): 1032–48. https://doi.org/10.1016/j.apenergy.2010.10.018; Marianne Ryghaug and Tomas Moe Skjølsvold, *Pilot Society and the Energy Transition: The Co-shaping of Innovation, Participation and Politics (1st ed.)* (Cham: Palgrave Pivot, 2021). https://doi.org/10.1007/978-3-030-61184-2.

7. Phil Johnstone, et al., 'Waves of disruption in clean energy transitions: Sociotechnical dimensions of system disruption in Germany and the United Kingdom,' *Energy Research & Social Science* 59 (January 2020): 101287. https://doi.org/10.1016/j.erss.2019.101287; Ryghaug and Skjølsvold, *Pilot Society.*

8. Canzler, et al., 'From "living lab" to strategic;' Gu and Feng, 'Heterogeneous choice;' Longo, Foiadelli, and Yaïci, 'Electric vehicles.'

and are strongly driven by national and European policy targets and measures.[9] It is also suggested to be an opportunity to engage traditional consumers more actively in energy-reduction debates and sustainability thinking.[10] For many, the symbolic qualities of EVs help make issues of mobility needs and energy scarcity concrete through, for instance, drivers becoming more aware of their driving and (re)fuelling habits in the light of their energy bill at home.[11] In some cases, this amplifies an interest in other decarbonisation opportunities (e.g., improving home energy efficiency or local energy production).[12]

The process of decarbonisation increases not only the local interconnection of the mobility and energy domains but also the risk of socio-spatial inequalities. After all, access to sustainable mobility and energy deliberately depends on the spatial properties of the places where people live. How can sustainable mobility, which is primarily aimed at shifting from motorised forms of mobility towards active (e.g., walking or cycling) and public modes of transport, also be ensured for people living in remote or poorly connected neighbourhoods with few local services?[13] The potential of sustainable energy production, which will be partly achieved through the local generation of electricity or heat, depends on local natural resource endowments/scarcity (e.g., hours of sunshine, opportunities

9. Longo, Foiadelli, and Yaïci, 'Electric vehicles;' Detlef P. van Vuuren, et al., *The implications of the Paris Climate Agreement for the Dutch climate policy objectives* (The Hague: PBL Netherlands Environmental Assessment Agency, 2017). http://bitly.ws/qw6r. The development and use of information and communication technology (ICT) and digitalisation are essential for realising the envisaged usage scenarios (within mobility/vehicle-to-grid settings as a passage to the development of distributed generation and smart grid), new roles and actor constellations (e.g. prosumers, energy cooperatives and increasing opportunities of ICT in the smart energy field), and business models (especially for energy trading within urban microgrids) that shape the intersectoral field (see Canzler, et al., 'From "living lab" to strategic;' Di Silvestre et al., 'How Decarbonization, Digitalization and Decentralization are changing key power infrastructures,' *Renewable and Sustainable Energy Reviews* 93 (October 2018): 483–98. https://doi.org/10.1016/j.rser.2018.05.068; Ryghaug and Skjølsvold, *Pilot Society.*)

10. Sanya Carley and David M Konisky, 'The justice and equity implications of the clean energy transition,' *Nature Energy* 5 (August 2020): 569–77. https://doi.org/10.1038/s41560-020-0641-6; Gu and Feng, 'Heterogeneous choice;' Ryghaug and Skjølsvold, *Pilot Society*.

11. Ryghaug and Skjølsvold, *Pilot Society*.

12. Ibid.; Carley and Konisky, 'The justice and equity.'

13. Erling Holden, Geoffrey Gilpin, and David Banister, 'Sustainable mobility at thirty,' *Sustainability* 11, no. 7 (April 2019): 1965. https://doi.org/10.3390/su11071965; Håkan Johansson, et al., 'A need for new methods in the paradigm shift from mobility to sustainable accessibility,' *Transportation Research Procedia* 14 (2016): 412–21. https://doi.org/10.1016/j.trpro.2016.05.093

for using geothermic, aqua-thermic, or anthropogenic heat sources). However, it also relies on physical space to install PV panels: people in flats with common roofs may have much fewer opportunities for installation than people with detached houses.[14] The interaction between mobility and energy transitions may even aggravate the growing inequalities. For instance, dwellers in terraced houses have more roof space to install PV panels, which provide sustainable energy onsite and allow them to drive their privately owned EVs at lower costs. On the other hand, those who live in rented high-rise apartment blocks on the outskirts lack such opportunities despite having more mobility and energy needs.

Problem Statement

Despite the great urgency for a rapid sustainability transformation of urban areas, current policy, and planning approaches to target urban challenges and meet different (inter)national goals are based on different ambitions and understandings of how cities operate and have led to fragmented approaches with suboptimal consequences for the larger urban context.[15] Policy processes are generally structured along organisational silos that result in policies that might be optimal for a certain sector but often undermine the effectiveness of others and are poorly integrated with (long-term) policy targets.[16] Sector-specific policies for mobility and energy, given the strong links between the two, may promote conflicting developments, which reduce the effectiveness of both transformations. For example, the need for a functioning all-electric energy system at home may necessitate

14. Teis Hansen and Lars Coenen, 'The geography of sustainability transitions: review, synthesis and reflections on an emergent research field,' *Environmental Innovation and Societal Transitions* 17 (December 2015): 92–109. https://doi.org/10.1016/j.eist.2014.11.001; Kammen and Sunter, 'City-integrated renewable energy.'

15. Jonas Bylund, 'Joint programming for urban transformations: the making of the JPI Urban Europe Strategic Research and Innovation Agenda,' *Urban Transformations* 2 (September 2020): 10. https://doi.org/10.1186/s42854-020-00012-y; Urban Europe, *Joint Call for Proposals for Research and Innovation Projects: Urban Transformation Capacities* (European Union: Urban Europe, 2020). http://bitly.ws/qxcj

16. Marc Dijk, et al., 'Policies tackling the "web of constraints" on resource efficient practices: The case of mobility,' *Sustainability: Science, Practice and Policy* 15, no. 1 (October 2019): 62–81. https://doi.org/10.1080/15487733.2019.1663992; Urban Europe, *Joint Call for Proposals*; Paula Kivimaa and Florian Kern, 'Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions,' *Research Policy* 45, no. 1 (February 2016): 205-17. https://doi.org/10.1016/j.respol.2015.09.008; Martin Larbi, *Green Urbanism in Contemporary Cities: A Socio-technical Transition Analysis, PhD diss.* University of Adelaide, 2019. https://hdl.handle.net/2440/120462 the ownership of EVs (as batteries for the intermittent self-generated electricity from PV panels), and thereby, it hinders a shift to car alternatives. On the other hand, there might be potential for synergistic developments such as achieving zero-carbon/emission, reliable services in both mobility and energy domains, or the shift to affordable EV sharing services. Whereas the integration of mobility and land-use policies has been on the research agenda already for many years,[17] the interference between mobility and energy policies has not been studied yet, and hence, how they can be made more coherent remains unclear.

Current approaches targeting sustainability challenges of urban mobility and energy systems do not only tend to stay within sectoral silos but also easily neglect socio-spatial inequalities of the transformation. Growing socio-spatial inequalities in terms of access to (sustainable) mobility and energy across various neighbourhoods create the real risk of mobility- and energy poverties. They are also greatly influenced by the spatial properties of the places in which people find themselves.[18] In the light of sustainability transformation, there is a need to make sure the transformation is also fair in a social sense.[19] Insights on the social impacts of mobility and energy transformations are crucial and therefore needed by policymakers and planners.

On account of the current predominance of policies that are sector-specific and do not take socio-spatial inequalities into account, there is a need for coherent and just policies or policy mixes. In this vein, we should (i) maximise synergies and minimise trade-offs in the effectiveness of sustainable urban mobility and energy transformations, and (ii) minimise socio-spatial inequalities that could result from both transformations. To support the development of such policies, there is a need for *ex-ante* evaluation and assessment of their

17. See Dominic Stead, 'Transport and land-use planning policy: really joined up?' *International Social Science Journal* 55 (June 2003): 333–47; David Banister, 'Viewpoint: Assessing the reality—Transport and land use planning to achieve sustainability,' *Journal of Transport and Land Use* 5, no. 3 (December 2012): 1–14. https://doi.org/10.5198/jtlu.v5i3.388

18. Neil Simcock and Caroline Mullen, 'Energy demand for everyday mobility and domestic life: Exploring the justice implications,' *Energy Research & Social Science* 18 (August 2016): 1–6. https://doi.org/10.1016/j.erss.2016.05.019

19. Susana Borrás and Jackob Edler, 'The roles of the state in the governance of socio-technical systems' transformation,' *Research Policy* 49, no. 5 (June 2020): 103971. https://doi.org/10.1016/j.respol.2020.103971 impacts on trade-offs and inequalities in the interconnected transformations, including relevant indicators. These indicators should both change over a longer period (i.e., a few decades) and provide insights into the socio-spatial heterogeneity, as shown in FIGURES 10 and 11.

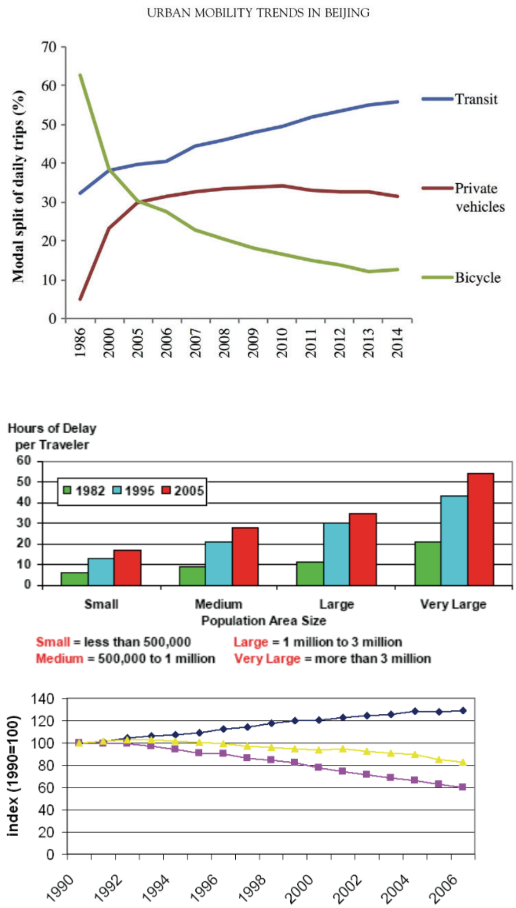

FIGURE 10. Examples of Time-Series of Possible Transformation Indicators (Left) and Impact Indicators (Right)

Source: Gao et al. and Dijk.[20]

20. Yuan Gao, et al., 'Transport and Mobility Trends in Beijing and Shanghai: Implications for Urban Passenger Transport Energy Transitions Worldwide,' in *Urban Energy Transition: Renewable Strategies for Cities and Regions (2nd ed.)*, ed. Peter Droege, (Amsterdam: Elsevier Ltd., 2018), 205–23. https://doi.org/10.1016/b978-0-08-102074-6.00025-5; Marc Dijk, *Innovation in Car Mobility: Coevolution of*

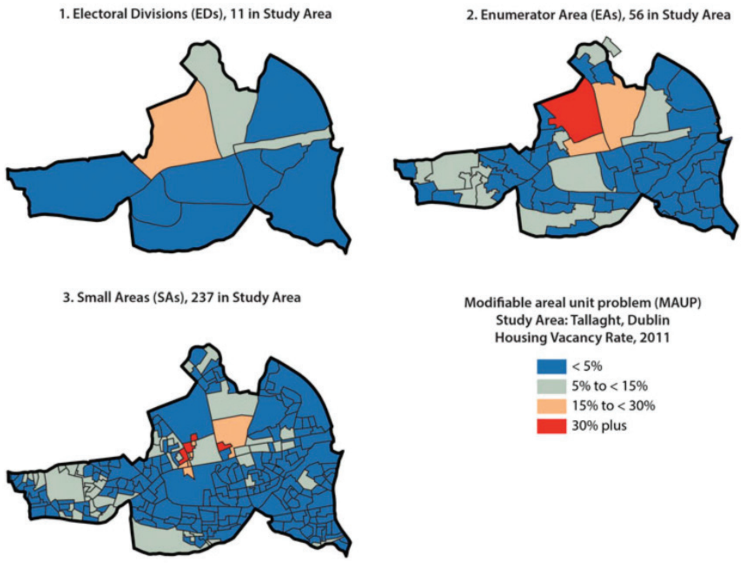

FIGURE 11. An Example of an Indicator (Housing Vacancy Rate as of 2011) at Statistical Geographies that Are Nested in the County Town of Tallaght in Dublin, Ireland

Source: Kitchin, Lauriault, and McArdle.[21]

Within the challenging policymaking context that is heavily constrained by time, budget, and span of control, these metrics for urban transformation ought to be comprehensive enough to capture the interdependencies and key environmental and socioeconomic impacts of mobility and energy transformations. Yet, they should not be too complex (i.e., they should not have too many indicators and not be too methodologically rigorous).

We hereby propose a methodological approach to developing a neighbourhood-level dashboard with a 'light' set of actionable indicators. Our purpose is to provide a much-needed simple assessment tool to address tensions and synergies in the interconnected urban mobility and energy transformations.

Demand and Supply under Sustainability Pressures. PhD diss. (Maastricht University, 2010). https://doi.org/10.26481/dis.20100923md

21. Rob Kitchin, Tracey P. Lauriault, and Gavin McArdle, 'Knowing and governing cities through urban indicators, city benchmarking and real-time dashboards,' *Regional Studies, Regional Science* 2, no. 1 (January 2015): 6–28. https://doi.org/10.1080/21681376.2014.983149

Likewise, we seek to focalise the interactions and potential effects of a policy package for said transformations. Additionally, we aim to incorporate the consideration of just urban transformation. Along these lines, the proposal is structured and organised into several sections within this chapter as follows. Section 8.2 discusses the literature reviews of urban transformation, urban assessment , and policy for transformation. In this light, the identification of knowledge gaps in the mobility–energy transformation nexus flags the need for metrics to understand and score the reciprocal sustainability impacts of the interconnected urban transformations at the neighbourhood level. Section 8.3 starts to sketch the contours of a manageable set of relevant indicators that should result in an indicator dashboard. The dashboard comprises some generic categories, which can be tailored to fit local specificities. It is intended to serve as a simple assessment tool that makes aggregated information on the cross-system interactions and sustainability implications of the interconnected urban transformations available in a meaningful way for transformation policy. Ideally, indicators are scored using both longitudinal and spatially explicit data to offer a more complete understanding of the mobility-energy nexus in sustainability transformation and bring to light the much-needed consideration of socio-spatial inequality. Lastly, Section 8.4 discusses the merits/potential of the approach for urban mobility policy and draws some conclusions.

8.2. Literature Review

Urban Transformation

Rapid decarbonisation towards carbon-neutrality by 2050 requires a transformation of urban systems in the coming three decades. In the urban context, we refer to transformations as fundamental and structural changes in urban practises that involve both material arrangements (e.g., technologies and infrastructures) and nonmaterial ones (e.g., conventions, norms, competencies, and cultures).[22] This generally involves nonlinear, complex, and long-term process-

22. Harriet Bulkeley, et al., eds. *Cities and Low Carbon Transitions (1st ed.)* (Abingdon: Routledge, 2011); Niki Frantzeskaki, et al., 'Urban Sustainability Transitions: The Dynamics and Opportunities of es of innovation, experimentation, upscaling, and institutional restructuring. In addition, it engages a wide range of actors who are not only on the receiving ends of urban processes but also engage in decision-making.[23]

Cities are large and growing sociotechnical ensembles and should thus be analysed as such.[24] Analyses of urban transformation have been a limited share in studies of socio-technical sustainability transformation in the past decades[25] but they have been recently increasing and seen as interesting avenues for a variety of research directions.[26] Still, more attention needs to be paid to local and spatial specificities from which transformations emerge within an urban context and unfold similarly/differently across locations, scales, and developmental stages.[27]

The past decades' advancement in the studies of socio-technical changes introduced a variety of heuristic devices to help researchers make sense of voluminous, multidimensional, and cross-disciplinary data. Such advances also allowed understanding approaches that are needed for a better understanding of transformation processes and pathways whilst making meaningful

Sustainability Transitions in Cities,' in *Urban Sustainability Transitions (1st ed.)*, eds. Niki Frantzeskaki, et al. (New York: Routledge, 2017), 1–22. https://doi.org/10.4324/9781315228389-1

23. Niki Frantzeskaki, et al., 'Urban Sustainability Transitions;' Thomas Lützkendorf and Maria Balouktsi, 'Assessing a sustainable urban development: Typology of indicators and sources of information,' *Procedia Environmental Sciences* 38 (2017): 546–53. https://doi.org/10.1016/j.proenv.2017.03.122; Bruno Turnheim, Paula Kivimaa, and Frans Berkhout, 'Beyond experiments,' in *Innovating Climate Governance: Moving Beyond Experiments*, eds. Bruno Turnheim, Paula Kivimaa, and Frans Berkhout, (Cambridge: Cambridge University Press, 2018), 1–26. https://doi.org/10.1017/9781108277679.002

24. Anique Hommels, 'Studying Obduracy in the City: Toward a Productive Fusion between Technology Studies and Urban Studies,' *Science, Technology, & Human Values* 30, no. 3 (July 2005): 323–51. https://doi.org/10.1177/0162243904271759

25. Jochen Markard, Rob Raven, and Bernhard Truffer, 'Sustainability transitions: An emerging field of research and its prospects,' *Research Policy* 41, no. 6 (July 2012): 955-67. https://doi.org/10.1016/j.respol.2012.02.013

26. Frantzeskaki, et al., 'Urban Sustainability Transitions;' Jonathan Köhler, et al., 'An agenda for sustainability transitions research: State of the art and future directions,' *Environmental Innovation and Societal Transitions* 31 (June 2019): 1–32. https://doi.org/10.1016/j.eist.2019.01.004; Ivan Savin and Jeroen van den Bergh, 'Main topics in EIST during its first decade: A computational-linguistic analysis,' *Environmental Innovation and Societal Transitions*, 41 (December 2021): 10–17. https://doi.org/10.1016/j.eist.2021.06.006

27. Frantzeskaki, et al., 'Urban Sustainability Transitions;' Frank W. Geels, et al., 'The enactment of socio-technical transition pathways: A reformulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990–2014),' *Research Policy* 45, no. 4 (May 2016): 896-913. https://doi.org/10.1016/j.respol.2016.01.015; Köhler, et al., 'An agenda for sustainability.'

comparisons and preventing data mis-gathering and misinformation.[28] For instance, the use of a conceptual framework that is rooted in innovation and evolutionary theories such as the multi-level perspective (MLP) has been prominent in the field due to its ability to explain long-term and far-reaching system change.[29] However, it has also criticised for poor insights into the local, spatial specificities of transformations.[30] At the urban level, the niche–regime dichotomy seems less productive because actors and practises are too entangled to be affiliated to only one of the two, and hence a more sensitive lens is needed.

This criticism has engendered the pursuit of a deeper local understanding of sociotechnical transformations through the lens of social practise theories (SPTS), which emerged from studies of sustainable consumption[31] and are increasingly applied in social science and energy research.[32] Unlike MLP, SPTS decentre technology and put the routines of people at the core. The theories refer to social practises as the routinised way people do things, such as how people travel, eat, shower, and heat their homes, etc. More recent elaborations on the basic three-element model of SPTS, i.e., 'meanings, materialities, and competences,'[33] have proven to be useful for analysing system change as transforming practises.

28. Benjamin K. Sovacool and David J. Hess, 'Ordering theories: Typologies and conceptual frameworks for sociotechnical change,' *Social Studies of Science* 47, no. 5 (June 2017): 703–50. https://doi.org/10.1177/0306312717709363

29. Köhler, et al., 'An agenda for sustainability;' Mohammadreza Zolfagharian, et al., 'Studying transitions: Past, present, and future,' *Research Policy* 48, no. 9 (November 2019): 103788. https://doi.org/10.1016/j.respol.2019.04.012

30. Hansen and Coenen, 'The geography of sustainability;' Mike Hodson and Simon Marvin, 'Urbanism in the anthropocene: Ecological urbanism or premium ecological enclaves?' *City* 14, no. 3 (June 2010): 298–313. https://doi.org/10.1080/13604813.2010.482277; James T. Murphy, 'Human geography and socio-technical transition studies: Promising intersections,' *Environmental Innovation and Societal Transitions* 17 (December 2015): 73–91. https://doi.org/10.1016/j.eist.2015.03.002

31. Filippo Corsini, et al., 'The advent of practice theories in research on sustainable consumption: Past, current and future directions of the field,' *Sustainability* 11, no. 2 (January 2019): 341. https://doi.org/10.3390/su11020341; Elizabeth Shove and Alan Warde, *Inconspicuous consumption: the sociology of consumption and the environment* (Lancaster: Lancaster University, 1998). http://bitly.ws/qwUF; Zolfagharian, et al., 'Studying transitions.'

32. Elisabeth M. C. Svennevik, Marc Dijk, and Peter Arnfalk, 'How do new mobility practices emerge? A comparative analysis of car-sharing in cities in Norway, Sweden and the Netherlands,' *Energy Research & Social Science* 82 (December 2021): 102305. https://doi.org/10.1016/j.erss.2021.102305

33. Elizabeth Shove, Mika Pantzar, and Matt Watson, *The Dynamics of Social Practice: Everyday Life and How it Changes* (London: SAGE Publications Ltd, 2012). https://doi.org/10.4135/9781446250655

Attention to local specificities has been demonstrated by recent applications of social-practise-based frameworks to unpacking transformations in different places such as Barnes Hofmeister and Keitsch's case of urban cycling, Dijk, Hommels, and Stoffers's case of urban car mobility and cycling, and Svennevik, Dijk, and Arnfalk's and Svennevik, Julsrud, and Farstad's cases of shared mobility.[34] These studies have examined certain new practise (such as car-sharing) in relation to established mobility practises. Moreover, they have addressed others such as housing, working, and shopping. In other words, they have conceptualised urban living as a patchwork of entangled practises as illustrated in FIGURE 12.

We expand Svennevik, Dijk, and Arnfalk's conceptual model, which primarily focuses on the urban mobility practises model, to include both mobility and energy practises' nexus (e.g., how people routinely travel, heat/cool their houses, and (re)fuel their vehicles, etc.) As shown in FIGURE 12, passenger mobility and household energy practises involve others on the users/travellers' side, but also grid operator and urban governance, among others, in relation to each other through partially shared infrastructure and partly interrelated meanings and competencies. As earlier studies have shown, such practises transform regarding each other and other (neighbouring) urban practises (e.g., working, housing, land-use planning, and parking operation in other cities, etc.). Although these earlier studies have offered new conceptualisations and ways of explaining urban transformation, they do not provide insight into the impacts of transformation in terms of environmental and social indicators. We turn to such literature subsequently in next section.

34. See Tobias Barnes Hofmeister and Martina Keitsch, 'Framing complexity in design through theories of social practice and structuration: A comparative case study of urban cycling,' *Proceedings of the Future Focused Thinking - DRS Conference*, eds. Paul Lloyd and Erick Bohemia, June 27–30, 2016, Brighton: Design Research Society. https://doi.org/10.21606/drs.2016.47; Dijk, Hommels, and Stoffers, 'Transformation of urban mobility practices in Maastricht (1950-1980): Co-evolution of cycling and car mobility,' presented at *Cycling Research Board Annual Meeting 2020, Eindhoven, October 26–28, 2020.*; Svennevik, Dijk, and Arnfalk, 'How do new mobility practices emerge;' Elisabeth M. C. Svennevik, Tom Erik Julsrud, and Eivind Farstad, 'From novelty to normality: Reproducing car-sharing practices in transitions to sustainable mobility,' *Sustainability*: *Science, Practice and Policy* 16, no. 1 (October 2020): 169–83. https://doi.org/10.1080/15487733.2020.1799624

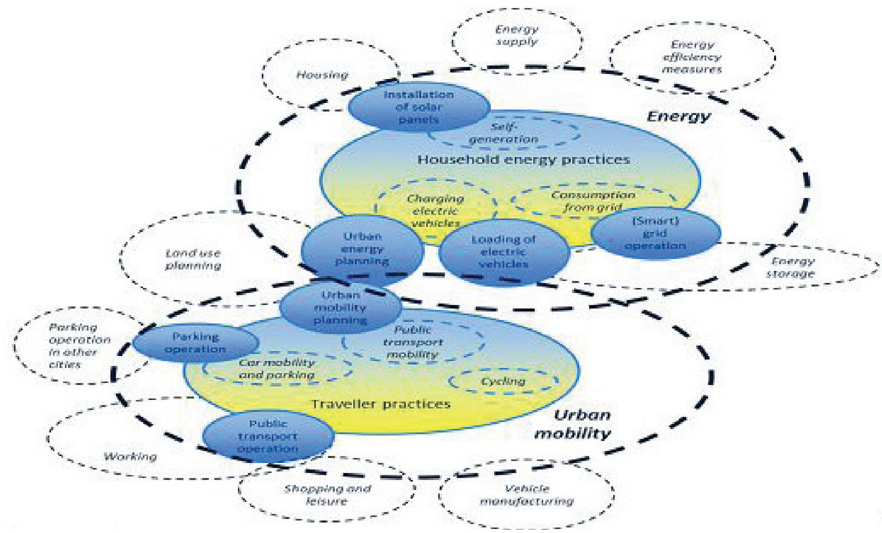

FIGURE 12. Urban Living Conceptualised as a Patchwork of Entangled Practises

Source: Prepared by authors based on the cases from Barnes Hofmeister and Keitsch; Dijk, Hommels, and Stoffers; Svennevik, Dijk, and Arnfalk; and Svennevik, Julsrud, and Farstad.[35]

Urban Assessment

Owing to the rise of sustainable development (SD) and urban managerialism, cities around the world have been routinely generating suites of indicators. They help not only systematically monitor and evaluate their progress and performance but also guide visions and strategies, support decision-making, and policy formulation, and inform urban governance.[36] Research on sustainability assessment (SA) for the urban context, which has been growing and receiving a strong interest across a wide spectrum of studies and cities in the past decade, tends to revolve around identifying and measuring many dozens of indicators

35. Svennevik, Julsrud, and Farstad, 'From novelty to normality.'

36. Matthew Cohen, 'A Systematic Review of Urban Sustainability Assessment Literature,' *Sustainability* 9, no. 11 (November 2017): 2048. https://doi.org/10.3390/su9112048; Rob Kitchin, Tracey P. Lauriault, and Gavin McArdle, 'Indicators, Benchmarking and Urban Informatics,' in *Understanding Spatial Media*, eds. Rob Kitchin, Tracey P. Lauriault, and Matthew W. Wilson (London: SAGE Publications Ltd., 2017), 119–26. https://doi.org/10.4135/9781526425850.n11 that are difficult for practitioners to employ.[37] The often-followed three-pillar approach (or triple bottom line) can lead to an oversimplification of such a complex problem as urban governance. This is because it impairs our ability to understand the interdependence across the sustainability pillars and is unable to capture all aspects of complex concepts such as SD or complex systems such as a city.[38] Analysing urban systems and improving their performance with respect to the sustainability pillars have largely relied on pertinent tools and methods from the fields of ecological economics, industrial ecology, and operations research. However, these involve simulation models with a high level of computational complexity and extensive data requirement.[39]

Policymakers, planners, and city managers are heavily constrained by time, budget, resources, and span of control (i.e., division of authority between local and national governments). At the same time, they are limited in technical knowledge and experience with respect to defining performance indicators and retrieval, collection, preparation, and interpretation of data.[40] They want to get a snapshot of how the city is performing in different areas but do not necessarily have the capacity and interest to comprehend technical or methodological details of indicator suites, which, despite their multitude, are typically developed for specific use purposes and thus, difficult to derive

37. Cohen, 'A Systematic Review;' Stanislav E. Shmelev and Irina A. Shmeleva, 'Global urban sustainability assessment: A multidimensional approach,' *Sustainable Development* 26, no. 6 (October 2018): 904–20. https://doi.org/10.1002/sd.1887; Pramit Verma and Akhilesh S. Raghubanshi, 'Urban sustainability indicators: Challenges and opportunities,' *Ecological Indicators* 93 (October 2018): 282–91. https://doi.org/10.1016/j.ecolind.2018.05.007

38. Cohen, 'A Systematic Review;' Kathryn M. Davidson, et al., 'Assessing urban sustainability from a social democratic perspective: A thematic approach,' *Local Environment* 17, no. 1 (November 2011): 57–73. https://doi.org/10.1080/13549839.2011.631990; Alexandros Gasparatos, Mohamed El-Haram, and Malcolm Horner, 'A critical review of reductionist approaches for assessing the progress towards sustainability,' *Environmental Impact Assessment Review* 28, no. 4–5 (May–June 2008): 286–311. https://doi.org/10.1016/j.eiar.2007.09.002

39. Shmelev and Shmeleva, 'Global urban sustainability assessment.'

40. Astrid Gühnemann, et al., *Monitoring and evaluation: Assessing the impact of measures and evaluating mobility planning processes* (Brussels: European Platform on Sustainable Urban Mobility Plans, 2016). http://bitly.ws/qwQy; Aapo Huovila, Peter Bosch, and Miimu Airaksinen, 'Comparative analysis of standardized indicators for Smart sustainable cities: What indicators and standards to use and when?' *Cities* 89 (June 2019): 141–53. https://doi.org/10.1016/j.cities.2019.01.029; Samuel Stehle and Rob Kitchin, 'Real-time and archival data visualisation techniques in city dashboards,' *International Journal of Geographical Information Science* 34, no. 2 (June 2019): 344–66. https://doi.org/10.1080/13658816.2019.1594823 actionable generalisations.[41] In seeking to reduce the complexity of urban systems, treating a city as a sum of simplified, one-dimensional indicators de-contextualises it from the wider set of relations that frame its development and the interconnections and interdependencies among them.[42] Benchmarking indicators for cross-city comparison assumes a normative standard by which cities should be assessed or judged rather than acknowledging the varying characteristics that determine how development goals are prioritised and how different strategies are applied to achieve sustainability in different cities.[43]

In theory, enhancing the efficiency and effectiveness of policymaking relies on the application of systemic evaluative rationality to public policy problems and *ex-ante* assessment based on empirical data, of which increasing diversity, availability, and openness in the last decade may create new opportunities.[44] In practise, policymakers hardly can do so. Although academic literature has currently provided limited insight on new data developments in policy practise, a review shows that the new types of big data are not replacing the usage of traditional ones, namely: surveys and statistics.[45] It suggests the dominance of traditional data, i.e., in descending order, survey data, statistical data, and geographical information system (GIS) data, for urban mobility policy assessment. Likewise, literature anticipates the continuation of their importance and

41. Pekka Halla, Romano Wyss, and Claudia R. Binder, 'Conceptualizing Urban Systems for Sustainability Assessment: Four Powerful Metaphors,' in *Sustainability Assessment of Urban Systems*, eds. Claudia R. Binder, Romano Wyss, and Emanuele Massaro (Cambridge: Cambridge University Press, 2020), 241–60. https://doi.org/10.1017/9781108574334.012; Huovila, Bosch, and Airaksinen, 'Comparative analysis;' Stehle and Kitchin, 'Real-time.'

42. Kitchin, Lauriault, and McArdle, 'Indicators, Benchmarking, Urban.'

43. Ainhoa Gonzalez, et al., 'Community of practice approach to developing urban sustainability indicators,' *Journal of Environmental Assessment Policy and Management* 13, no. 4 (December 2011): 591–617. https://doi.org/10.1142/s1464333211004024; Kitchin, Lauriault, and McArdle, 'Indicators, Benchmarking, Urban.'

44. Michael Howlett and Sarah Giest, 'The policy-making process,' in *Routledge Handbook of Public Policy (1st ed.)*, eds. Eduardo Araral, et al. (London: Routledge, 2012), 17–28. https://doi.org/10.4324/9780203097571-8; Xu Liu and Marc Dijk, 'The role of data in sustainability assessment of urban mobility policies,' *Data & Policy* 4 (January 2022): e2. https://doi.org/10.1017/dap.2021.32; Organisation for Economic Cooperation and Development, OECD, *Better Policies for Sustainable Development 2016: A New Framework for Policy Coherence* (Paris: OECD Publishing, 2016). https://doi.org/10.1787/9789264256996-en

45. Liu and Dijk, 'role of data in sustainability.'

relevance in said context despite the surging attention to and availability of open, location-based big data.

In spite of the greater availability of (open) data, sustainability monitoring studies have concluded that more indicators do not necessarily deliver more actionable understanding. On the contrary, these have proposed embracing the principle of decision relevance ('why to measure') in designing monitoring schemes ('less is more').[46] The selection of tools and indicators for urban assessment has room to benefit from an explicit conceptualisation of the complex assessment problem. This conceptualisation helps deliver a coverage of necessary aspects of sustainability, especially those ones that have been hitherto under-appreciated/addressed, and signals whether the interplay of said aspects supports or compromises the ability of the system to sustain itself in the long run in a transparent, unbiased, unarbitrary, conscious, and reflexive fashion.[47]

Transformation Policy

Concerning policy, studies of sustainability transformation have called for a broad mix of research and innovation policies with particular attention being paid to societal experimentation. Scholars have proposed frameworks that align such experiments with long-term policy objectives often accompanied by long-term targets and plans to achieve them, which can be supported by strategic visioning and foresight processes.[48]

Molas-Gallart et al. propose a formative approach to the evaluation of what is called transformative innovation policies (TIPS).[49] TIPS are generally policy mixes that seek to enable a transformation. Their evaluation approach is a

46. Todd S. Rosenstock, et al., 'When less is more: Innovations for tracking progress toward global targets,' *Current Opinion in Environmental Sustainability* 26–27 (June 2017): 54–61. https://doi.org/10.1016/j.cosust.2017.02.010

47. Jasper Großkurth, *Regional Sustainability: Tools for Integrated Governance. PhD diss.* (Maastricht University, 2008). https://doi.org/10.26481/dis.20081209jg; Halla, Wyss, and Binder, 'Conceptualizing Urban Systems.'

48. See Derk Loorbach, *Transition Management: New Mode of Governance for Sustainable Development* (Utrech: International Books, 2007). https://hdl.handle.net/1765/10200

49. Jordi Molas-Gallart, et al., 'A Formative Approach to the Evaluation of Transformative Innovation Policy,' *Research Evaluation* 30, no. 4 (October 2021): 431–42. https://doi.org/10.1093/reseval/rvab016 generic and complex 'sociotechnical transformation' framework that includes the description of the situation to be transformed, the desired goals, and the steps linking them.[50] The intermediate steps consist of 'supporting individual and organisational learning' through a process of 'reflexive monitoring and evaluation' of policy interventions.[51] It includes the expected relations between the resources invested in intervention and their effects and the assumptions under which they expect such effects.[52] Molas-Gallart et al.'s approach is well-thought-out from a learning perspective. A disadvantage is that the strong emphasis on learning processes and *ex-post* and *ex-ante* policy assessment is at odds with the current logic of the public sector. The 'projectification of policy practise'[53] has only constrained learning processes and there is hardly any capacity for policy assessment at lower levels of government. Therefore, there is a need for simpler tools that do support the transformation process but do not depend on a cultural shift towards 'reflexive monitoring and evaluation.'

We aim to develop a 'transformation dashboard' for specific domains (i.e., transport and energy) and geographic scope (i.e., urban level). Such a dashboard can be helpful when urban governments have only adopted the aim to shift to low-carbon transport and energy practises. It could be an element in Molas-Gallart et al.'s evaluation approach but, again, it does not assume a particular evaluation and learning approach.

Our concern is that the dashboard does reflect the systemic character of the policy aim. Yet, our approach does not include the formulation and evaluation of specific policy interventions and associated learning processes. We seek to depict the overall status of the transformation process and, accordingly, help make policies in transport and energy more coherent and ensure a fair distribution of transformation across the city.

50. Molas-Gallart, et al., 'A Formative Approach.'

51. Ibid.

52. Ibid.

53. Damian Hodgson, et al., eds. *The Projectification of the Public Sector (1st ed.)* (New York: Routledge, 2019). https://doi.org/10.4324/9781315098586

8.3. Metrics for Urban Transformation

What indicators can give an insight into how urban passenger mobility and energy practises transform over a few decades? Objective indicators from both sides of the urban mobility–energy transformation nexus include, but are not limited to, sharing personal car trips or kilometres driven versus that of other mobility modes, ownership, and use of internal combustion engine vehicles. They also imply the electric counterpart and share of dwellings with local renewable energy generation (e.g., home-installed, or community-based PV panels). In the quest for such indicators, the interference between mobility and energy systems should be viewed as a hypothesis that needs further investigation rather than strict guidance for the search. The increasing interference and its potential to transform the urban landscape is plausible in principle and evinces the growing need and opportunities to align both sides of the nexus (e.g., smart loading of EVs). Nevertheless, the realisation of such interference may still be limited in certain cities or countries and thus, it might not be sufficiently significant when expressed as objective indicators.

Sociotechnical transformation pathways that unfold over a few decades can be mapped through time series of such indicators (see examples in FIGURE 10), either retrospectively or prospectively (i.e., as scenarios). While the use of longitudinal data resonates well with the temporal nature of social changes and is common in this field of research, it should also be complemented by cross-sectional elaborations of complexities and interrelationships between specific variables and sub-elements/systems that are associated with the transformation at hand.[54] In other words, transformative pathways ought to be formulated in terms of endogenous enactment and ideally embrace both characterisation of the overall course of development (global/outside-in) and depiction of immediate action processes that create short-run developmental episodes (local/inside-out).[55]

54. Zolfagharian, et al., 'Studying transitions.'

55. Geels, et al., 'The enactment of socio-technical.'

As noted, the reviewed studies of urban transformations lack the indication of the sustainability levels of said transformations, and therefore, we propose an indicator dashboard that can be employed as a simple *ex-ante* or *ex-post* policy support tool. Our suggested approach to indicator-based urban assessment lies in the integration of several mobility and energy aspects of urban living, how they lead to sustainability impacts, and how they reflect fundamental change over time in the whole urban system.

Sustainability is a normative yet subjective and ambiguous concept.[56] It concerns cross-system interactions that are complex, dynamic, and interdependent and subject to contextuality, contingency, value judgement, and interpretation.[57] The key challenge of indicator-based SA thus entails the dilemma of being general enough to ground it in the core features of sustainability whilst specific enough to describe the context- and place-specificities at hand.[58] Therefore, we propose an indicator dashboard with some generic categories that can be tailored to fit local specificities.

To select indicators for a particular locality, we recommend employing both analysis of written sources such as policy reports, databases, statistical yearbooks, and local media in combination with interviews. Clearly, this assumes the availability of reliable data at a sufficient level of spatiotemporal resolution. It also requires interaction with urban policymakers, planners, and practitioners, etc., who have first-hand insights into local policy and sustainability priorities. When indicators have been selected, various data sources, for example, a combination of survey data and big data (e.g., real-time traffic, a global positioning system (GPS), mobile phone, and social media data) can be used to score the indicators.

56. Angus Morrison-Saunders, et al., 'Towards sustainability assessment follow-up,' *Environmental Impact Assessment Review* 45 (February 2014): 38–45. https://doi.org/10.1016/j.eiar.2013.12.001; Verma and Raghubanshi, 'Urban sustainability indicators.'

57. Paul M. Weaver and Jan Rotmans, 'Integrated sustainability assessment: What is it, why do it and how?' *International Journal of Innovation and Sustainable Development* 1, no. 4 (May 2007): 284–303. https://doi.org/10.1504/ijisd.2006.013732

58. Großkurth, *Regional Sustainability.*

We propose that the dashboard is utilised 'not just as a tool for *ex post facto* research, but to also guide sustainability visions and strategies for sustainable urban development.'[59] The rapid evolution of soft computing techniques and availability of computational resources for urban systems research increasingly require engineering and scientific disciplines. This is to work with political decision-makers within a complex setting in which multiple and conflicting objectives, preferences, and value systems must be addressed in noncontentious and noncontroversial manners.[60]

Grounded in complexity and multiplicity, the multi-criteria analysis (MCA) resonates with the nature of urban systems[61] and forms the underlying frame of the dashboard. The principle of MCA lies in evaluating certain subjects against a set of predefined criteria without necessarily enforcing the translation of their results into a common scale depending on the perspective of sustainability and the degree of compensability between the criteria.[62] Similarly, techniques such as the analytic hierarchy process (AHP) incorporate both quantitative and qualitative aspects of a problem and systematically derive their relative importance by means of pairwise comparisons. Thereby, AHP can be used for transparent accounting and comprehension of different values, trade-offs, and priorities.[63]

Selection, development, and interpretation of indicators in relation to the overall understanding of the complex system at hand can be facilitated with a theme/issue-based framework. Its flexible structure allows for the addition of cross-cutting (sub)themes and articulates linkages between the indicators,

59. Cohen, 'A Systematic Review': 10.

60. Catherine D. Gamper and Catrinel Turcanu, 'Multi-criteria analysis: A tool for going beyond monetization?' In *The Tools of Policy Formulation: Actors, Capacities, Venues and Effects*, eds. Andrew J. Jordan and John R. Turnpenny (Cheltenham: Edward Elgar Publishing, 2015), 121–41. https://doi.org/10.4337/9781783477043.00017; Gasparatos, El-Haram, and Horner, 'A critical review,' 286–311; Manfren and Costa, 'Paradigm shift in urban.'

61. Stanislav E. Shmelev and Irina A. Shmeleva, 'Methods and indicators for urban sustainability assessment,' in *Sustainable Cities Reimagined (1st ed.)*, ed. Stanislav E Shmelev (Abingdon: Routledge, 2020), 1–25. https://doi.org/10.4324/9780429287725-1; Shmelev and Shmeleva, 'Global urban sustainability assessment.'

62. Gamper and Turcanu, 'Multi-criteria analysis;' Gasparatos, El-Haram, and Horner, 'A critical review.'

63. Michela Nardo, et al., *Tools for Composite Indicators Building* (Ispra: European Communities, 2005). http://bitly.ws/qxn8 their relevance to policy aims and processes, and the overarching goal of integrated urban sustainability.[64] Employing this framework to organise the practise-informed transformation indicators around key themes diverges from the conventional three-pillar framework, which can improve the manageability of the urban assessment process and is widely used by national and local governments. Still, it oversimplifies the fundamentally co-dependent reality of urban systems, in which assessment elements interact with one another in a nested hierarchy and do not always conveniently fit in one sustainability pillar, and do not necessarily reflect the experience and perceptions of residents and users of urban space.[65] Put it simple, the three sustainability pillars may serve as 'blind-spot checkers' that checks the balance of the selected indicators in the light of the three pillars of sustainability rather than the starting point for selecting indicators.

Possible indicators to include in the dashboard encompass those that are commonly associated with impacts of urban living on the environment such as air quality and resource consumption. The former can be represented by the atmospheric concentration of common urban air pollutants (such as coarse and fine particulate matters, soot, ozone, and nitrogen dioxide), the record of violation of air quality standards, and the presence of plans and measures of safeguarding air quality.[66] The resource consumption can be spoken of as tangible resources (e.g., energy, biodiversity, and land), of which depletion of non-renewable kinds should be limited and smart(er) uses of the renewable substitutes ought to be enhanced. In addition, said consumption might be

64. Jiangu Wu and Tong Wu, 'Sustainability Indicators and Indices: An Overview,' in *Handbook of Sustainable Management*, eds. Christian N. Madu and Chu-Hua Kuei (Singapore: Imperial College Press, 2012), 65–86. https://doi.org/10.1142/8164

65. Davidson, et al., 'Assessing urban sustainability;' Wu and Wu, 'Sustainability Indicators and Indices.'

66. Dominique Gillis, Ivana Semanjski, and Dirk Lauwers, 'How to monitor sustainable mobility in cities? Literature review in the frame of creating a set of sustainable mobility indicators,' *Sustainability* 8, no. 1 (December 2015): 29. https://doi.org/10.3390/su8010029; Todd Litman, *Well Measured: Developing Indicators for Sustainable and Livable Transport Planning* (Victoria: Victoria Transport Policy Institute, 2021). https://www.vtpi.org/wellmeas.pdf; Peter-Paul Pichler, et al., 'Reducing urban greenhouse gas footprints,' *Scientific Reports* 7 (November 2017): 14659. https://doi.org/10.1038/s41598-017-15303-x; World Business Council for Sustainable Development, WBCSD, 'Methodology and Indicator Calculation Method for Sustainable Urban Mobility,' Eltis. October 10, 2017. http://bitly.ws/qw62; World Health Organization, WHO. 'Ambient (outdoor) air pollution,' September 22, 2021. http://bitly.ws/qw5J regarded in the light of intangible resources (e.g., respect for local traditions and the sense of community).[67]

Built on a more integrative interpretation of urban sustainability, the dashboard also encompasses indicators that have implications for quality of life, social equity, and environmental justice. For example, accessibility and affordability address individuals' capability to access basic and developmental needs (i.e., education, healthcare, transportation, housing, recreation of individuals, capital, transfer of knowledge, and career opportunities).[68] In mobility terms, these indicators address several elements of urban transport planning (e.g., connectivity of roads and paths, land use patterns, and availability of mobility options/substitutes) and can be used to anticipate inclusive urban living, especially for low-income, disadvantaged, and (mobility-)impaired individuals.[69] The emerging consideration of justness in low-carbon transformations also induces the novel interpretation of these indicators in terms of the access to affordable and reliable energy and decarbonisation opportunities (e.g., adoption of low-carbon and energy-efficient technologies and participation in energy-related decision-making processes). The latter are evidently uneven across socioeconomic and demographic groups.[70]

Urban forms, geography, socioeconomic conditions, and urbanisation dynamics influence energy needs, availability of energy resources, burdens, and access to low-carbon and energy-efficient alternatives. It is important to note that these aspects do not only vary from one city to another but also from one neighbourhood to another within the same city.[71] Integrating geographically explicit data instead of solely treating a city as an internally homogeneous entity enables the identification of disproportionate burdens and unequal access

67. Litman, *Well Measured*; Sodiq, et al., 'Towards modern sustainable cities.'

68. Didem Dizdaroğlu, 'The role of indicator-based sustainability assessment in policy and the decision-making process: A review and outlook,' *Sustainability* 9, no. 6 (June 2017): 1018. https://doi.org/10.3390/su9061018; Sodiq, et al., 'Towards modern sustainable cities.'

69. Sodiq, et al., 'Towards modern sustainable cities;' Litman, *Well Measured*.

70. Carley and Konisky, 'The justice and equity.'

71. Carley and Konisky, 'The justice and equity;' Kammen and Sunter, 'City-integrated renewable energy,' 922–28.

to resources and decarbonisation opportunities. This also sheds understanding of how these distributional consequences of sustainability transformation effect other aspects of urban living at large.[72]

Driven by the inadequate consideration of social justice in the mainstream urban sustainability discourses,[73] our indicator dashboard explicitly specifies 'distribution across neighbourhoods' as a separate and crosscutting subtheme (see FIGURE 13). Each of the selected indicators should be spatialised across the city's census wards (or statistical sectors, e.g., neighbourhoods, districts, boroughs, and postcodes, etc.) as exemplified in FIGURE 11. These are viable scales at which interactions within urban systems and between several aspects of urban sustainability and the socio-spatial manifestation of sustainability transformation can be meaningfully captured and assessed. This is investigated by some of the recent socio-spatial correlation studies on agglomeration externalities in terms of accessibility versus air pollution and clean technology privilege in terms of EV diffusion.[74] In this line, a general-purpose GIS software such as *ArcGIS Pro* comprises key functions and easily referenced web-based services that enable the analyses of multiple categories of spatially explicit data from different time frames. This software can be used to develop a comprehensive understanding of urban sustainability in relation to real-world composition, configuration, and patterns.[75]

72. Carley and Konisky, 'The justice and equity;' Lu Huang, Jianguo Wu, and Lijao Yan, 'Defining and measuring urban sustainability: A review of indicators,' *Landscape Ecology* 30 (May 2015): 1175–93. https://doi.org/10.1007/s10980-015-0208-2

73. Vanesa Castán Broto and Linda Westman, 'Just sustainabilities and local action: Evidence from 400 flagship initiatives,' *Local Environment* 22, no. 5 (November 2016): 635–50. https://doi.org/10.1080/13549839.2016.1248379

74. See Nicola da Schio, Kobe Boussauw, and Joren Sansen, 'Accessibility versus air pollution: A geography of externalities in the Brussels agglomeration,' *Cities* 84 (January 2019): 178–89. https://doi.org/10.1016/j.cities.2018.08.006; Jean León Boucher and Walter Mérida, 'Inflated lives and a clean tech privilege in Washington State: Policy amidst spatialized affluence,' *Energy Research & Social Science* 85 (March 2022): 102418. https://doi.org/10.1016/j.erss.2021.102418

75. David J. Maguire, 'ArcGIS: General-Purpose GIS Software,' in *Encyclopedia of GIS*¸ eds. Shashi Shekhar, Hui Xiong, and Xun Zhou (Cham: Springer, 2017). https://doi.org/10.1007/978-3-319-17885-1_68

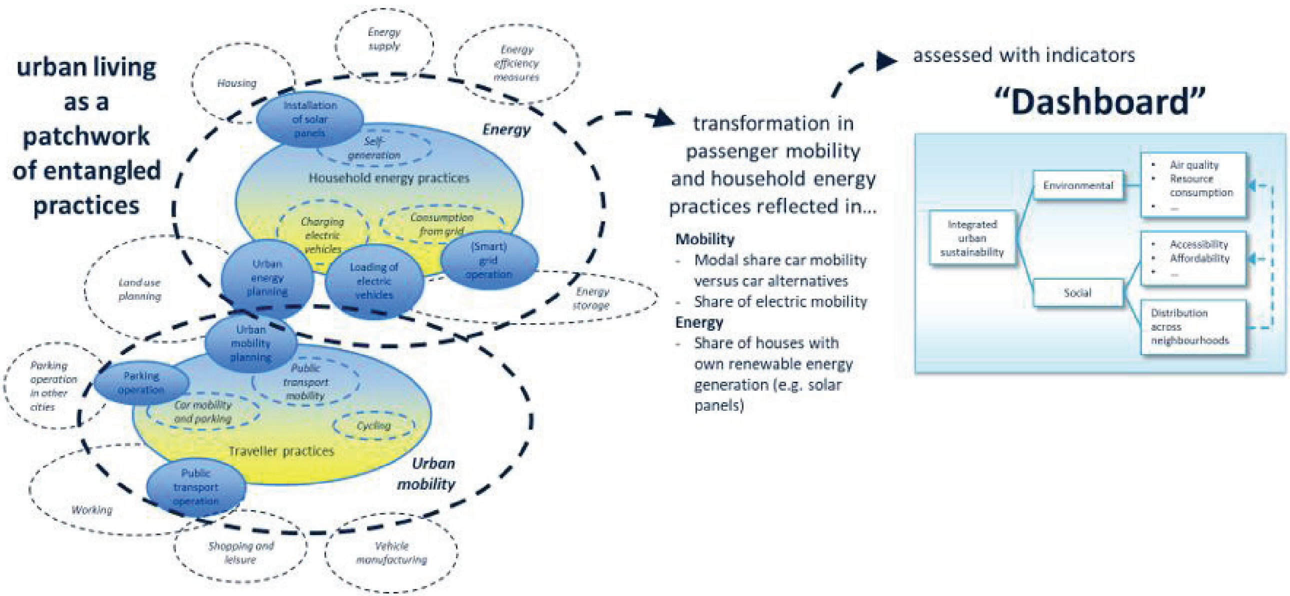

FIGURE 13. Urban Living Conceptualised as a Patchwork of Entangled Practises with Attention to Transformation in Passenger Mobility and Household Energy Practises and Assessed with an Indicator Dashboard

Source: Prepared by authors.

8.4. Conclusions and Discussion

Current approaches targeting environmental challenges not only tend to stay within sectoral silos but also easily neglect socio-spatial inequalities of the transformation like the risk of mobility and energy poverty and growing inequalities in access to mobility and energy across the various neighbourhoods. The traditionally separated mobility and energy fields have been increasingly interconnected through the pressing global and urban sustainability challenges that necessitate simultaneous decarbonisation of transport and energy systems. An emerging point of interest is how these transformations can be shaped inclusively. We have posited an indicator dashboard for urban transformations encompassing key interactions at the mobility–energy nexus that can support urban practitioners in their governance challenges of managing the interconnected transformations whilst safeguarding their fairness. We propose to apply a limited number (e.g., about ten) of indicators to reflect both the transformation process and its impacts. As a digestible coverage of sustainability aspects on both sides of the nexus, the contextualised indicator dashboard illuminates the effects of the complex cross-system interactions in relation to the overarching goal of integrated urban sustainability in a useful way for policymakers. The longitudinal mapping of the urban transformation pathways, which is potentially useful for supporting policy visions and planning, is accompanied by socio-spatial cross-sectional insights to generate a more complete understanding of the transformation.

Sustainability-related problems can never be addressed adequately from a single perspective.[76] Stakeholders' participation is principal to the goal-setting step of indicator development, which is much less of a research focus and presently lacks integration of citizen- and expert-led approaches due to ambiguity in the definition of sustainability.[77] In practise, this step of indicator development can be enhanced through co-creation with local actors. Widely promoted as the principal mechanism for realising societal transformations in pursuit of

76. Weaver and Rotmans, 'Integrated sustainability assessment.'

77. Verma and Raghubanshi, 'Urban sustainability indicators.'

various sustainability goals, cocreation encompasses acknowledging the importance of the local level. This entails accommodating meaningful collaboration and transparency, moderating actor groups and interests, and pursuing inclusiveness based on consideration of realistically available resources and respect for existing initiatives.[78] The co-creation approach links scholarly research to socio-political perceptions and requirements, the gap between which poses a major challenge for urban governance research.[79]

Although this chapter is predominantly research-driven, the next step of developing our proposed dashboard should take place at the policy-research interface and discuss a particular local context through processes of co-creation.[80] Realising sustainability transformation in real-world contexts involves dealing with a collection of competing goals and strategies. These hamper both the achievement of one another and the progress of the transformations and thus, require a balanced approach to enable the cocreated decisions whilst advancing the transformation processes.[81] Urban planners, local authorities, and other key stakeholders can benefit from understanding their scope of influence and the outcomes of their possibilities of action in relation to positive progress in the area to which each indicator is assigned, provided that the indicators are tailored to the local conditions and contextual knowledge at hand.[82]

The dashboard, whose indicators should be aligned to policy goals and vice versa, informs the synergistic and contradictory effects of decision-making

78. Sigrun Kabisch, et al., 'New urban transitions towards sustainability: Addressing SDG challenges (research and implementation tasks and topics from the perspective of the Scientific Advisory Board (SAB) of the Joint Programming Initiative (JPI) Urban Europe),' *Sustainability* 11, no. 8 (April 2019): 2242. https://doi.org/10.3390/su11082242

79. Nuno F. da Cruz, Philipp Rode, and Michael McQuarrie, 'New urban governance: A review of current themes and future priorities,' *Journal of Urban Affairs* 41, no. 1 (August 2018): 1–19. https://doi.org/10.1080/07352166.2018.1499416

80. Niki Frantzeskaki and Nadja Kabisch, 'Designing a knowledge co-production operating space for urban environmental governance—Lessons from Rotterdam, Netherlands and Berlin, Germany,' *Environmental Science & Policy* 62 (August 2016): 90–98. https://doi.org/10.1016/j.envsci.2016.01.010; Emma Puerari, et al., 'Co-creation dynamics in Urban Living Labs,' *Sustainability* 10, no. 6 (June 2018): 1893. https://doi.org/10.3390/su10061893

81. Kabisch, et al., 'New urban transitions;' Paula Kivimaa, et al., 'Passing the baton: How intermediaries advance sustainability transitions in different phases,' *Environmental Innovation and Societal Transitions* 31 (June 2019): 110–25. https://doi.org/10.1016/j.eist.2019.01.001

82. Lützkendorf and Balouktsi, 'Assessing a sustainable urban.'

for the enveloping socio-technical systems that can leverage transformative change in urban development practises.[83] It can provide policymakers and planners with insight into the impacts of mobility and energy transformations to effectively evaluate and adjust policies, plans, urban structures, and societal functions. When applying the dashboard in such policy discussion, a consequence table can be developed (see TABLE 12).

TABLE 12. Quantitative Consequences

Criteria → ↓ Means	C1	C2	C3	C4
M1	+		–	
M2	+	+		
M3	–			+
M4		+	+	
M5		+/–	–	
M6			+	+

Source: Taken from Enserink et al.[84]

The table above focuses decision-makers on the evaluation and comparison of attributes based on the proxies for the things that matter. Likewise, it transparently informs needed information base, potential trade-offs, uncertainties, and relative priorities.[85] This sort of decision-sketching/support tool could be populated with either qualitative or quantitative estimates of expected

83. Alexander P. N. van der Jagt, et al. 'Nature-based innovation systems,' *Environmental Innovation and Societal Transitions* 35 (June 2020): 202–16. https://doi.org/10.1016/j.eist.2019.09.005; Arnim Wiek and Claudia Binder, 'Solution spaces for decision-making—A sustainability assessment tool for city-regions,' *Environmental Impact Assessment Review* 25, no. 6 (August 2005): 589–608. https://doi.org/10.1016/j.eiar.2004.09.009

84. Bert Enserink, et al., *Policy Analysis of Multi-Actor Systems* (The Hague: Lemma, 2010).

85. Lee Failing, Robin Gregory, and Michael Harstone, 'Integrating science and local knowledge in environmental risk management: A decision-focused approach,' *Ecological Economics* 64, no. 1 (October 2007): 47–60. https://doi.org/10.1016/j.ecolecon.2007.03.010; Robin Gregory, et al., *Structured Decision Making: A Practical Guide to Environmental Management Choices (1st ed.)* (Chichester: Blackwell Publishing Ltd., 2012).

consequences or impact to help make coherent and internally consistent judgements and to insulate against the pitfalls of unaided decision-making.[86]

Our metrics have a significant parallel with Keirstead and Leach's approach to urban sustainability indicators (USIs).[87] It recognises urban services (e.g., transport and energy) as integral to multiple aspects of urban life and sustainability agenda and the use of such services as a derived demand, based on which the different influences of energy-consuming activities (e.g., household number and car ownership), the resource requirement to meet such demand (e.g., consumption of petrol, natural gas and electricity resources), and the resultant impacts of consumption (e.g., fuel poverty and carbon dioxide emissions) on the overall urban sustainability goals can be distinguished.[88] Such a framework could help policymakers select useful indicators and avoid irrelevant ones, identify parts of the service chain that needs high-quality data, relate the indicators to specific areas of policy responsibility, and identify causal links between metrics. Development and assessment of indicators in relation to policy aims and available high-quality data can be followed by a number of niche-expansion strategies. Examples of these are: replicating the experiment to build experience, promoting policies that are complementary to the niche, and maintaining the networks that have arisen around the niche. These ideas might inspire innovation researchers' work on the diffusion of new technologies (e.g., green electricity tariff or ecolabelling scheme or solar energy systems) to further develop sustainability endeavours.[89]

While indicator selection methodology is heavily focused in both this chapter and the past decade's research on the application of USIs, attention should also be given to understudied aspects such as reporting findings and sustaining

86. Liibeth A. Acosta, et al., 'Using scenarios and models to inform decision making in policy design and implementation,' in *The Methodological Assessment Report on Scenarios and Models of Biodiversity and Ecosystem Services*¸ eds. Simon Ferrier, et al. (Bonn: Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2016), 35–82.

87. James Keirstead and Matt Leach, 'Bridging the gaps between theory and practice: a service niche approach to urban sustainability indicators,' *Sustainable Development* 16, no. 5 (October 2007): 329–40. https://doi.org/10.1002/sd.349

88. Ibid.

89. Ibid.

the indicator framework. Equally important is to address the emerging aspect of the application and universal applicability/acceptability of findings in actual situations that lead to challenges lying in the numerous governments' administrative machinery and will to implement them.[90] Finally, whilst still lacking, a comparison between case studies is encouraged to test the SA tool's robustness at highlighting the disparity in political (in)stability, availability of infrastructure, and local resources or lack thereof, urban challenges, priorities, practises, and institutions. Accordingly, such comparative exercises could promote urban sustainability in different regions across the world.[91]

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