Multi-system dynamics in sustainability transitions

Extended call for papers for a special issue in *Environmental Innovation and Societal Transitions*

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Introduction

As transitions in more and more systems start to accelerate (Markard et al., 2020; Rogge & Goedeking, 2024), they are increasingly characterized by dynamics that span across multiple systems. For example, achieving net-zero emissions by midcentury is a goal that forces a strategic shift of attention from decarbonizing one system at the time, to understanding and advancing parallel interacting transitions in several systems. Moreover, transitions in heating, industry, and transport to a large extent rely on low-carbon electricity and the transition of the electricity system itself (Andersen et al., 2023; Rosenbloom, 2020). Meanwhile, as new multi-purpose technologies such as hydrogen technologies, battery, or carbon capture innovations are deployed, multiple socio-technical systems get affected and new interdependencies emerge (Finstad & Dahl Andersen, 2023; Löhr & Chlebna, 2023). Fundamentally, multi-system dynamics are increasingly pervasive phenomena in contemporary sustainability transitions and there is growing recognition in transitions studies that a response to the sustainability crisis requires interconnected shifts in multiple systems.

In this special issue, we tentatively define multi-system dynamics as transition processes that involve interactions among actors, technologies and institutions across two or more socio-technical systems. Consequently, multi-system transitions can be understood as transition processes taking place interdependently and shaping each other in multiple systems.

State of the art

Research on multi-system dynamics has a long history in the transitions field. Beginning from the study on the emergence of rock'n'roll as the interaction of radio and recording regimes (Geels, 2007), an early wave of transitions studies engaged with multi-system interactions in various ways. This included introducing the notions of structural and functional couplings between systems (Konrad et al., 2008), a typology of multi-regime interactions, e.g. competition, symbiosis, integration, spill-over (Raven & Verbong, 2009), and a typology of system interactions in

transitions (Papachristos et al., 2013). Despite such key insights, the field largely came to focus on single system transitions in the 2010s. Work on multi-system interactions remained comparatively scarce (e.g. Sutherland et al., 2015). Furthermore, early studies typically attempted to extend the conceptual frameworks developed for single system transitions such as the multi-level perspective to multi-system dynamics. While the relevance of phenomena that do not easily fit the single-system frame, e.g. long waves, were occasionally recognized in the literature (Köhler, 2012), empirical and conceptual work in these lines remained scarce.

Driven by the growing empirical manifestations and importance of multi-system dynamics in real-world transitions, there has been a resurgence of research on the topic in recent years. In particular, there has been a broadening of the scope of multi-system interactions from the study of connections between single system transitions towards multi-system transitions (Nykamp et al., 2023) and the macro-level outcomes of these processes, e.g. work on deep transitions, 'meta-regimes' and industrial modernity (Kanger & Schot, 2019; Kemp et al., 2022; Schot & Kanger, 2018). Studies have also shed a light on more processual understanding of the creation of couplings between systems (Andersen & Geels, 2023) and broadened attention from "horizontal" connections to also considering "vertical" ones, i.e. technology value chains (Gong & Andersen, 2024; Mäkitie et al., 2022; Stephan et al., 2017). Increasing attention has been put on the empirical study of multi-system innovations and multi-purpose technologies, such as vehicle-to-grid technology (e.g. Bakhuis et al., 2024), hydrogen technologies (Ohlendorf et al. 2023; Löhr et al. 2024), carbon capture (e.g. Finstad & Dahl Andersen, 2023) and general-purpose technologies as AI (John et al., 2022). Researchers have analyzed the role of actors of multi-system dynamics, such as system entanglers connecting different systems (Löhr & Chlebna, 2023), actors diversifying across systems (e.g. Mäkitie et al., 2018), and the role of policy and governance in multi-system settings (e.g. Löhr et al., 2024; Rogge & Goedeking, 2024).

Topics and contributions of interest in this special issue

These recent studies reflect the breadth of issues associated with multi-system dynamics (Gong & Andersen, 2024). While there is therefore a growing consensus around the importance of multi-system dynamics, recent studies have also generated many new questions and led to a rather fragmented field of research without much conceptual consolidation and critical reflection on underlying assumptions. Against this background, the goal of this special issue is to advance and consolidate the knowledge base on multi-system dynamics in transitions studies by revisiting and taking stock of central approaches and concepts as well as exploring new emerging questions. Therefore, the guest editors invite (but do not limit this SI to) contributions that engage with the following topics:

1. System types, scope, and boundaries. Existing studies look at different types and constellations of systems, such as sociotechnical systems, complexes of systems, sectors, or value chains. This variety implies different criteria for and ways to draw the system boundaries, e.g., according to societal function, organizational fields, or intensity of interactions between system elements. We

also note that existing research mainly looks at interactions between two systems, leaving us with less knowledge about more expansive multi-system dynamics. Questions of interest therefore include:

- How do we set criteria for when a phenomenon is multi-system in nature?
- (How) should we rethink and revisit criteria for system delimitation and explore implications for multi-system analysis? What role should spatial system delineation play?
- Overall, what is, if any, the conceptual and methodological core to these studies?

2. Theoretical (dis)continuity. We need to critically reflect on the frameworks needed to grasp the particularities of multi-system dynamics. Key questions include:

- What phenomena can be analyzed through the conceptual extension of existing frameworks such as the Multi-level Perspective or Technological Innovation Systems? When and why do we need entirely new conceptual approaches?
- When should studies zoom in, e.g., on interactions mechanisms and causal processes, or zoom out, e.g., in observing the general patterns and the macro-level outcomes of multi-system transitions? What are the pros and cons of these choices for our analyses? How could they be integrated?

3. System co-evolution and destabilization. We still lack insights into how systems co-evolve over longer time periods including how actor reorientation or institutional change in one system can cause changes in other systems giving rise to cross-system positive feedback loops and tipping cascades of reactive sequences. Likewise, while there has been a lot of attention to increasing interactions and new couplings across systems, still little is known about multi-system dynamics in the context of system decline and destabilization, including system decoupling. Important questions comprise:

- How do systems co-evolve over longer time periods?
- How do systems decouple, decline, or destabilize? And how does it affect system interaction?

4. Policymaking in multi-system contexts. Few studies address the new challenges and opportunities that multi-system contexts pose to actors engaging in policymaking across system boundaries, ranging from power struggles to policy integration or the formation of consistent and coherent policy mixes. The following questions may be considered:

- How do actors integrate different (policy) systems or align competing interests across (policy) systems?
- How to explain policy formation across systems?

Timeline

- Journal submission open – Early March, 2025
- Journal submission closes – 31 August 2025

- 1st round peer review completed – 30 October 2025
- Revisions and resubmissions - 15 December 2025
- 2nd round peer review completed – 31 January 2026
- Full special issue publication – 15 March 2026

References

Andersen, A. D., & Geels, F. W. (2023). Multi-system dynamics and the speed of net-zero transitions: Identifying causal processes related to technologies, actors, and institutions. *Energy Research & Social Science*, *102*, 103178.

Andersen, A. D., Geels, F. W., Coenen, L., Hanson, J., Korsnes, M., Linnerud, K., Makitie, T., Nordholm, A., Ryghaug, M., & Skjolsvold, T. (2023). Faster, broader, and deeper! Suggested directions for research on net-zero transitions. *Oxford Open Energy*, *2*, oiad007.

Bakhuis, J., Kamp, L. M., Barbour, N., & Chappin, É. J. L. (2024). Frameworks for multi-system innovation analysis from a sociotechnical perspective: A systematic literature review. *Technological Forecasting and Social Change*, *201*, 123266.

Finstad, J., & Dahl Andersen, A. (2023). Multi-sector technology diffusion in urgent net-zero transitions: Niche splintering in carbon capture technology. *Technological Forecasting and Social Change*, *194*, 122696. https://doi.org/https://doi.org/10.1016/j.techfore.2023.122696

Geels, F. W. (2007). Analysing the breakthrough of rock 'n'roll (1930–1970) Multi-regime interaction and reconfiguration in the multi-level perspective. *Technological Forecasting and Social Change*, *74*(8), 1411-1431.

Gong, H., & Andersen, A. D. (2024). The role of material resources for rapid technology diffusion in net-zero transitions: Insights from EV lithium-ion battery Technological Innovation System in China. *Technological forecasting and social change*, *200*, 123141. https://doi.org/https://doi.org/10.1016/j.techfore.2023.123141

John, N., Wesseling, J. H., Worrell, E., & Hekkert, M. (2022). How key-enabling technologies' regimes influence sociotechnical transitions: The impact of artificial intelligence on decarbonization in the steel industry. *Journal of Cleaner Production*, *370*, 133624.

Kanger, L., & Schot, J. (2019). Deep transitions: Theorizing the long-term patterns of socio-technical change. *Environmental Innovation and Societal Transitions*, *32*, 7-21. https://doi.org/https://doi.org/10.1016/j.eist.2018.07.006

Kemp, R., Pel, B., Scholl, C., & Boons, F. (2022). Diversifying deep transitions: Accounting for socio-economic directionality. *Environmental Innovation and Societal Transitions*, *44*, 110-124. https://doi.org/https://doi.org/10.1016/j.eist.2022.06.002

Köhler, J. (2012). A comparison of the neo-Schumpeterian theory of Kondratiev waves and the multi-level perspective on transitions. *Environmental Innovation and Societal Transitions*, *3*, 1-15.

Konrad, K., Truffer, B., & Voß, J.-P. (2008). Multi-regime dynamics in the analysis of sectoral transformation potentials: evidence from German utility sectors. *Journal of Cleaner Production*, *16*(11), 1190-1202.

Löhr, M., & Chlebna, C. (2023). Multi-system interactions in hydrogen-based sector coupling projects: System entanglers as key actors. *Energy Research & Social Science*, *105*, 103282.

Löhr, M., Markard, J., & Ohlendorf, N. (2024). (Un)usual advocacy coalitions in a multi-system setting: the case of hydrogen in Germany. *Policy Sciences*, *57*(3), 567-597. https://doi.org/10.1007/s11077-024-09536-7

Mäkitie, T., Andersen, A. D., Hanson, J., Normann, H. E., & Thune, T. M. (2018). Established sectors expediting clean technology industries? The Norwegian oil and gas sector's influence on offshore wind power. *Journal of Cleaner Production*, *177*, 813-823. https://doi.org/https://doi.org/10.1016/j.jclepro.2017.12.209

Mäkitie, T., Hanson, J., Steen, M., Hansen, T., & Andersen, A. D. (2022). Complementarity formation mechanisms in technology value chains. *Research Policy*, *51*(7), 104559. https://doi.org/https://doi.org/10.1016/j.respol.2022.104559

Markard, J., Geels, F. W., & Raven, R. (2020). Challenges in the acceleration of sustainability transitions. *Environmental Research Letters*, *15*(8), 081001.

Nykamp, H., Andersen, A. D., & Geels, F. W. (2023). Low-carbon electrification as a multi-system transition: a socio-technical analysis of Norwegian maritime transport, construction, and chemical sectors. *Environmental Research Letters*, *18*(9), 094059.

Papachristos, G., Sofianos, A., & Adamides, E. (2013). System interactions in socio-technical transitions: Extending the multi-level perspective. *Environmental Innovation and Societal Transitions*, *7*, 53-69.

Raven, R. P., & Verbong, G. P. (2009). Boundary crossing innovations: Case studies from the energy domain. *Technology in society*, *31*(1), 85-93.

Rogge, K. S., & Goedeking, N. (2024). Challenges in accelerating net-zero transitions: insights from transport electrification in Germany and California. *Environmental Research Letters*, *19*(4), 044007.

Rosenbloom, D. (2020). Engaging with multi-system interactions in sustainability transitions: A comment on the transitions research agenda. *Environmental Innovation and Societal Transitions*, *34*, 336-340.

Schot, J., & Kanger, L. (2018). Deep transitions: Emergence, acceleration, stabilization and directionality. *Research Policy*, *47*(6), 1045-1059. https://doi.org/https://doi.org/10.1016/j.respol.2018.03.009

Stephan, A., Schmidt, T. S., Bening, C. R., & Hoffmann, V. H. (2017). The sectoral configuration of technological innovation systems: Patterns of knowledge development and diffusion in the lithium-ion battery technology in Japan. *Research Policy*, *46*(4), 709-723. https://doi.org/https://doi.org/10.1016/j.respol.2017.01.009

Sutherland, L.-A., Peter, S., & Zagata, L. (2015). Conceptualising multi-regime interactions: The role of the agriculture sector in renewable energy transitions. *Research Policy*, *44*(8), 1543-1554.