Open access • Journal Article • DOI:10.1126/SCIENCE.AAO3760

Sociotechnical transitions for deep decarbonization. — Source link

Frank W. Geels, Benjamin K. Sovacool, Benjamin K. Sovacool, Tim Schwanen ...+1 more authors

Institutions: University of Manchester, University of Sussex, Aarhus University, University of Oxford

Published on: 22 Sep 2017 - Science (American Association for the Advancement of Science)

Sociotechnical transitions for deep decarbonization

Article (Accepted Version)

Accelerating sociotechnical transitions for deep decarbonization

Paper for "Policy Forum" for *Science*

Frank W. Geels[1,] Benjamin K. Sovacool[2,3], Tim Schwanen[4], Steve Sorrell[2]

1 University of Manchester
2 University of Sussex
3 Aarhus University
4 University of Oxford

Summary: The acceleration of low-carbon transitions across the sociotechnical systems of electricity, heat, buildings, manufacturing, and transport requires new conceptual approaches, analytical foci, and policy recommendations.

Rapid and deep reductions in greenhouse gas emission are needed to avoid dangerous climate change. To provide a reasonable (66%) chance of limiting global temperature increases to below 2°C, global energy-related carbon emissions must peak by 2020 and fall by more than 70% in the next 35 years.[1] This implies a tripling of the annual rate of energy efficiency improvement, retrofitting the entire building stock, generating 95% of electricity from low-carbon sources by 2050 and shifting almost entirely towards electric cars.

Deep decarbonization will necessitate low-carbon transitions across electricity, transport, heat, industrial, forestry and agricultural systems. But despite recent rapid growth in renewable electricity generation, the rate of progress towards this wider goal remains slow. Moreover, many energy and climate researchers remain wedded to disciplinary approaches that focus on a single piece of the low-carbon transition puzzle.[2] A case in point is a recent Policy Forum[3] proposing a 'carbon law' that will guarantee that zero-emissions are reached. This model-based prescription focuses on policy, but not politics, culture, business, and social factors, thus avoiding many crucial real-world drivers of accelerated transitions.

This Policy Forum presents a 'sociotechnical' framework that addresses the multi-dimensionality of the deep decarbonization challenge and shows how co-evolutionary interactions between technologies and multiple societal groups can accelerate low-carbon transitions. We organize this approach around four lessons, emphasizing factors that receive less attention in techno-economic and modeling approaches.

1. Focus on socio-technical systems rather than individual elements

Rapid and deep decarbonization requires a transformation of 'sociotechnical systems' – the interlinked mix of technologies, infrastructures, organizations, markets, regulations and user practices that together deliver societal functions such as personal mobility. These systems have developed over many decades, and the alignment and co-evolution of their elements makes them resistant to change.

A framework for understanding the multiple causal mechanisms characterizing system transitions is the *Multi-Level Perspective* (MLP).[4] This sees transitions as driven by interactions between three analytical levels: a) the *sociotechnical system* itself, which is stabilized by lock-in mechanisms, but experiences incremental improvements along path-dependent trajectories; b) *niche innovations*, which differ radically from the dominant existing system, but are able to gain a foothold in particular geographical areas or market niches, or with the help of targeted policy support; and c) exogenous ('*landscape*') developments such as slow-changing trends (e.g. demographics, ideologies) or shocks (e.g. elections, economic crises, wars) that destabilize the system and facilitate the breakthrough of niche innovations. Instead of single drivers, the MLP's key point is that transitions come about through the alignment of processes within and between these three levels - illustrated diagrammatically in Figure 1.

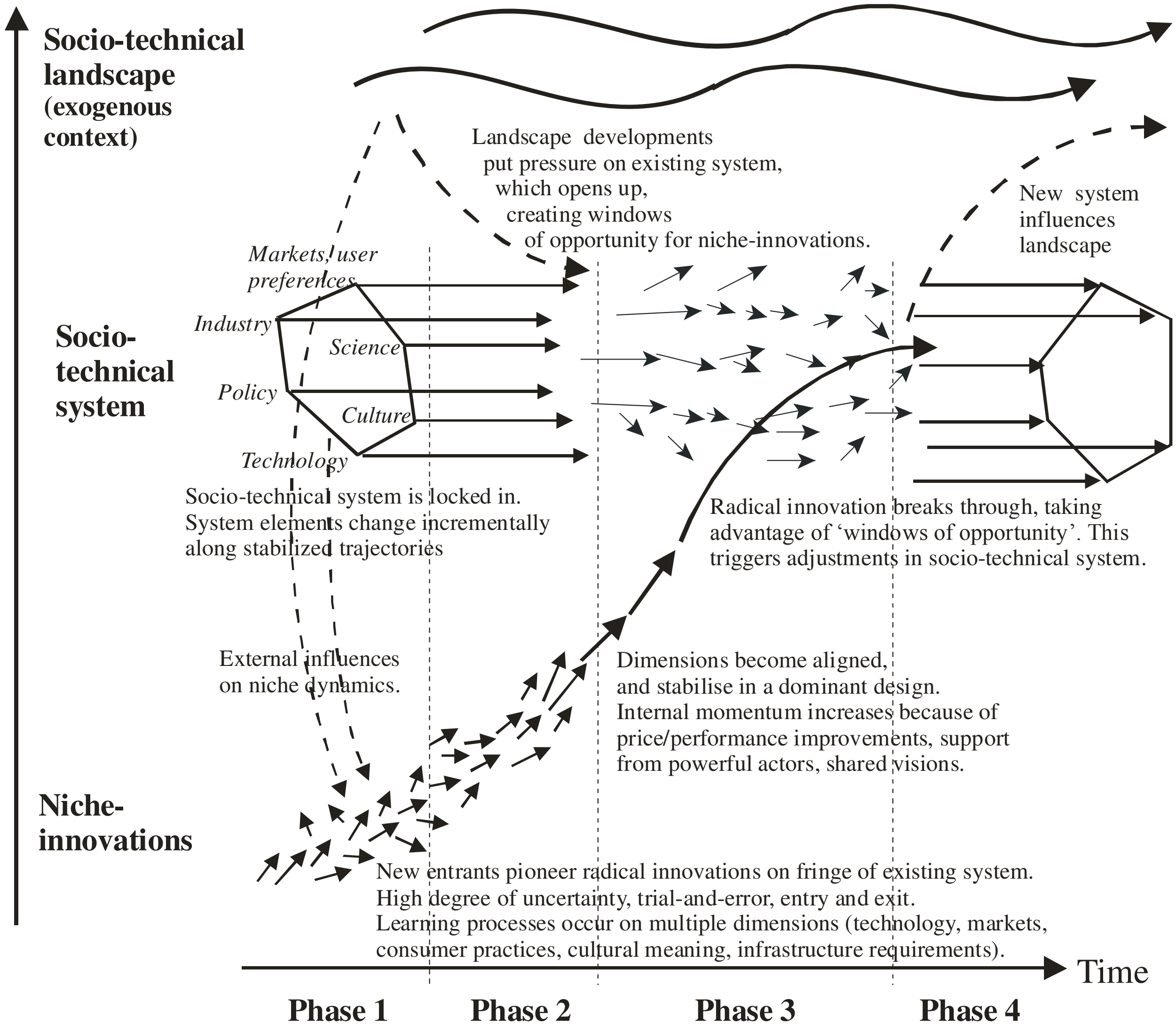

Figure 1: Multi-level perspective on sociotechnical transitions (adjusted from ref. 4)

The acceleration of socio-technical transitions in the third phase involves three mutually reinforcing processes: growing internal momentum of niche-innovations, weakening of existing systems (represented with small diverging arrows in Figure 1), and growing exogenous pressures. The resulting socio-technical transitions go beyond the adoption of new technologies and include investment in new infrastructures, the establishment of new markets, the development of new social preferences and the adjustment of user practices.

The unfolding German energy transition, for instance, involved the increasing momentum of wind, photovoltaic and biogas technologies due to price/performance improvements, support from industrial coalitions (e.g. metal and machine-building, turbine manufacturing, farming), positive cultural framing and generous policy support (particularly through the 2000 Renewable Energy Act, which established 20-year long, attractive feed-in-tariffs).[5] The existing system, especially nuclear power, faced long-standing tensions due to a powerful anti-nuclear movement, negative cultural discourses framing nuclear power as existential threat and utilities as large monopolists, and political pressure from the Labor/Green Party government coalition (1998-2005). The 2011 Fukushima accident was an external, destabilizing shock triggering the decision to phase-out nuclear power and embrace energy transition as a political goal.

The case highlights that accelerated low-carbon transitions depend on both techno-economic improvements, and social, political and cultural processes, including the development of positive or negative discourses.[6] Although the Labor/Green Party coalition could not foresee later fortuitous alignments, the 2000 Renewable Energy Act was deliberately introduced as a long-term transition strategy, which created protected market niches that stimulated technological learning and improvement, the growth of new industries (based on an ecological modernization vision), and the entry of new firms (which keener to drive renewables than incumbent regime actors).[5] The case also demonstrates that acceleration depends heavily on country-specific dynamics in political coalitions, industry strategy, cultural discourses and civil society pressures. There is no "one-size-fits-all" blueprint for accelerating low-carbon transitions.

2. Aligning multiple innovations and systems

Socio-technical transitions gain momentum when multiple innovations are linked together, improving the functionality of each and acting in combination to reconfigure systems. The shale gas revolution, for instance, accelerated when seismic imaging, horizontal drilling, and hydraulic fracturing were combined. Likewise, accelerated low-carbon transitions in electricity depend not only on the momentum of renewable energy innovations like wind, solar-PV and bio-energy[7], but also on complementary innovations including: energy storage (e.g. batteries, flywheels, compressed air, pumped hydro); smarter grids (to enhance flexibility and grid management); demand response (e.g. new tariffs, smart meters and intelligent loads); network expansion (to increase capacity, connect remote renewables and link to neighboring systems); and new business models and market arrangements (such as energy-only markets and capacity markets to ensure system security).

Linkages *between* systems may also drive deep decarbonization. Vehicle-to-grid configurations, for instance, can facilitate the diffusion of battery-electric vehicles and mitigate the intermittency problems of wind and solar electricity if car batteries support load balancing.[8] District heating systems can be coupled with electricity and gas grids, leading to integrated systems in which thermal energy fulfill storage and back-up functions for intermittent electricity.[9] Urban planning and transport systems can be integrated via transit-oriented development (building mixed-use areas around public transport stops), compact cities, and intermodal transport (which facilitates mode-switching with seamless transfer facilities, smart cards, and aligned time-tables).[10]

Attention must thus be broadened towards interactions between multiple innovations and socio-technical systems. 'Whole system' models have started to do so but often focus on energy flows and technical linkages, giving limited consideration to consumer acceptance, business models and socio-political drivers.

3. Societal and business support

Low-carbon transitions are often seen as a techno-economic implementation challenge, justified by climate science and driven by R&D and carbon pricing. But accelerated transitions also depend upon social acceptance and business support.[11] Public support is crucial for effective transition policies because "whatever can be done through the State will depend upon generating widespread political support from citizens".[12] Low-carbon transitions in mobility, agro-food, heat and buildings will also involve millions of citizens who need to modify their purchase decisions, user practices, beliefs, cultural conventions and skills. To motivate citizens, financial incentives and information about climate change threats need to be complemented by *positive* discourses about the economic, social and cultural benefits of low-carbon innovations.

Business support is essential because the development and deployment of low-carbon innovations depends upon the technical skills, organizational capabilities and financial resources of the private sector. Green industries and supply chains can also solidify political coalitions supporting ambitious climate policies and provide a counterweight to incumbents.[13] Furthermore, technological progress can drive climate policy by providing solutions or altering economic interests.[14] Shale gas and solar-PV developments, for instance, altered the US and Chinese positions in the international climate negotiations.

Societal and business support can be built gradually in the first and second phase of transitions (Figure 1), through bottom-up learning processes, participatory governance and polycentric stakeholder engagement.[15] Business support also depends on low-carbon market opportunities, which can be enhanced by policies (subsidies, tax credits, standards) or changing consumer preferences. Once in place, societal and business support improves resilience against political setbacks. In the Danish electricity and heat transition, for instance, reductions in renewable energy policies by a newly elected government (2001) triggered a bottom-up backlash from local energy cooperatives, citizen groups, NGOs, manufacturers, and SMEs, which enabled policy restoration several years later.[16] In the UK, the low-carbon transition is predominantly a top-down project involving policymakers and incumbents. The narrower societal support base creates the risk that the weakened climate policy by the Conservative government since 2015 will derail the unfolding transition.

4. Phasing out existing systems

Socio-technical transitions can also be accelerated by actively phasing out existing technologies, supply chains, and systems that lock-in emissions for decades.[17] The UK transition to smokeless solid fuels and gas, for example, was accelerated by the 1956 Clean Air Act, which allowed cities to create smokeless zones where coal use was banned. This drastic policy was introduced after the 1952 Great London Smog (resulting in 4000 excess deaths) created public pressure and the political will for change.[18] Another example is the 2009 European Commission decision to phase-out incandescent light bulbs, which accelerated the shift to compact fluorescents and LEDs. French and UK governments have announced plans to phase-out petrol and diesel cars by 2040. Moreover, the UK intends to phase out unabated coal-fired power generation by 2025 (if feasible alternatives are available).

Phasing out existing systems accelerates transitions by creating space for niche-innovations and removing barriers to their diffusion. The phase-out of carbon-intensive systems is also essential to prevent the bulk of fossil fuel reserves from being burned, which would obliterate the 2ºC target. This phase-out will be challenging since it threatens the largest and most powerful global industries (e.g. oil, automobiles, electric utilities, agro-food, steel), which will fight to protect their vested economic and political interests.

Phase-out policies can take several forms:[19] bans or regulations that stipulate emission reductions from specific technologies or sectors; targeted financial incentives to encourage decarbonization; or removal of implicit or explicit subsidies for high-carbon systems, which globally range from \$1.9 to \$5.3 trillion per year.[20] Whatever policies are used, it is important to consider transitional strategies such as phased tightening of regulations, financial compensation, retraining of personnel or redevelopment programs for disadvantaged regions.[21] Such policies may reduce the likelihood of resistance to transitions. Dutch policymakers, for instance, alleviated the disruption of the 1960s transition from coal to gas by retraining miners and assisting the company's transformation to a chemicals firm.[22] Unassisted UK mine closures, in contrast, disrupted entire communities in the 1980s, creating persistent social problems. Similar fears are presently motivating US and German coal mining communities to resist low-carbon transitions, leading to political backlashes.

Policy implications

General policy implications for accelerated low-carbon transitions can be derived from the above lessons. First, innovation is a crucial accelerator, because it can improve technological price/performance characteristics, generate new functionalities and open up new markets, disrupt existing systems, galvanize public enthusiasm around positive visions, and nurture green business coalitions, which may subsequently support stronger climate policies. Sector-specific innovation policy is therefore at least as important as economy-wide climate policy, and may in fact enable it.[13] Innovation policies (R&D subsidies, feed-in-tariffs, demonstration projects, adoption subsidies) are also more politically feasible than economy-wide carbon taxes, because the former provide concentrated benefits, whereas the latter imposes costs on many voters and industries.[11]

Second, low-carbon innovation policy should not only focus on R&D and financial incentives, but also on experimentation, learning, stakeholder involvement, social acceptance, positive discourses and opportunities for new entrants. Without sufficient societal and business support, it is difficult to accelerate or sustain low-carbon transitions for long periods.

Third, stronger alignments are necessary between innovation policy and sector-specific policy (in electricity, heat, transport, urban planning) to explore the potential of interacting technologies and systems, both through foresight methods and on-the-ground demonstration projects. Polycentric efforts in particular, which connect and align scales, actors, and responsibilities, tend to be more effective than efforts contained to one scale.

Fourth, since the emergence of innovations takes time, accelerated low-carbon transitions also involves actively phasing out existing systems. This requires careful political attention to the social and distributional consequences of decarbonization.

Deep decarbonization requires complementing model-based analysis with socio-technical research. While the former analyzes technically feasible least-cost pathways, the latter addresses innovation processes, business strategies, social acceptance, cultural discourses and political struggles, which are difficult to model but crucial in real-world transitions. While full integration of both approaches is not possible, productive bridging strategies may enable policy strategies that are both cost-effective and socio-politically feasible.[23]

RFERENCES AND NOTES

[1] IEA/IRENA. *Perspectives for the Energy Transition: Investment Needs for a Low-carbon Energy System* (IEA/IRENA, 2017).

[2] P.C. Stern, B.K. Sovacool, T. Dietz. Towards a science of climate and energy choices. *Nat. Clim. Chang.* **6**, 547-555 (2016).

[3] J. Rockstrom *et al*. A roadmap for rapid decarbonization. *Science* **355**, 1269-121 (2017).

[4] F.W. Geels, J.W. Schot. Typology of sociotechnical transition pathways. *Res. Policy*, **36**, 399 (2007).

[5] F.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). *Res. Policy* **45**, 896 (2016).

[6] D. Rosenbloom, H. Berton, J. Meadowcroft. Framing the sun: A discursive approach to understanding multi-dimensional interactions within socio-technical transitions through the case of solar electricity in Ontario, Canada, *Res Policy* **45**, 1275–1290 (2016).

[7] B. Obama, The irreversible momentum of clean energy. *Science* **355**, 126 (2017).

[8] B.K. Sovacool, J. Axsen, W., Kempton. The future promise of vehicle-to-grid integration: A sociotechnical review and research agenda. *Ann. Rev. Env. Resour.* (in press, 2017).

[9] H., Lund *et al*. 4th generation district heating (4GDH): Integrating smart thermal grids into future sustainable energy systems. *Energy* **68**, 1–11 (2014).

[10] F. Creutzig *et al*. Urban infrastructure choices structure climate solutions, *Nat. Clim. Chang.* **6**, 1054-1056 (2016).

[11] L. Hughes, J. Urpelainen. Interests, institutions, and climate policy: Explaining the choice of policy instruments for the energy sector. *Environ. Sci. Policy* **54**, 52-63 (2015).

[12] Giddens, A. *The Politics of Climate Change*. Cambridge: Polity Press (2009).

[13] J. Meckling, N., Kelsey, E. Biber, E., J. Zysman. Winning coalitions for climate policy. *Science*, **349**, 1170-1171 (2015).

[14] T.S. Schmidt, S. Sewerin. Technology as a driver of climate and energy politics. *Nat. Energ.* **2**, 17084 (2017).

[15] M.A. Brown, B.K. Sovacool. *Climate Change and Global Energy Security: Technology and Policy Options* (MIT Press, 2011).

[16] P.O. Eikeland, T.H.J Inderberg. Energy system transformation and long-term interest constellations in Denmark: can agency beat structure? *Energ. Res. Soc. Sci.* **11**, 164-173 (2016).

[17] S.J. Davis, R.H. Socolow. Commitment accounting of CO2 Emissions. *Environ. Res. Lett.* **9**, 111001.

[18] B. Turnheim, F.W. Geels. Regime destabilisation as the flipside of energy transitions: Lessons from the history of the British coal industry (1913–1997) *Energ. Policy* **50**, 35-49 (2012).

[19] P. Kivimaa, F. Kern, F. Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. *Res. Policy* **45**, 205-217 (2016).

[20] B.K. Sovacool, Reviewing, reforming, and rethinking global energy subsidies: towards a political economy research agenda. *Ecol. Econ.* **135**, 150-163 (2017).

[21] J.J. Cordes, B.A. Weisbroc. When government programs create inequities: A guide to compensation policies. *J. Policy Anal. Manag* **4**,178-195 (1985).

[22] V.V. Moharir. *Process of Public Policy-Making in the Netherlands: A Case Study of the Dutch Government's Policy for Closing Down the Coal Mines in South Limburg, 1965-1975* (The Hague, Institute of Social Studies, 1979).

[23] F.W. Geels, F. Berkhout, D. Van Vuuren. Bridging analytical approaches for low-carbon transitions. *Nat Clim Chang*. ***6***, 576-583 (2016).