

# Sustainability Transition Theories: Perpetuating or Breaking with the Status Quo

**Author:** Dr. Katharina Biely

**Affiliation:** Knowledge Technology and Innovation Group, Wageningen University and Research, Wageningen 6700EW, The Netherlands

Orcid ID: <https://orcid.org/0000-0002-7060-0242>

**Keywords:** Thomas Kuhn, Sustainability Transition, Socio-ecological transition, Socio-technological transition

## **Abstract:**

How scientists frame problems impact the solutions offered. Since the late 1940s, with the help of scientists, progress and development have been equated with modernization, the adoption of technologies, and economic growth. Contrasting to this technocentric view on development and progress an ecocentric view has developed since the 1960s. This was, amongst others, the result of increasing environmental problems. Despite the criticism of technocentric views and increasing evidence that human societies are not reaching their environmental and social goals, technocentric views have remained predominant in the sustainable development discourse. Using a Kuhnian lens, the divide between technocentric and ecocentric perspectives can be framed as distinct paradigms within the sustainable development discourse. This paper outlines the continuation of the ecocentric versus technocentric worldview divide within sustainability transition studies. It also shows that the technocentric view is predominant. The paper concludes that socio-technical transition theory fails to break with technocentric and growth-focused approaches to progress and development.

## 1. Introduction

Human societies have created unsustainable systems. The landmark publication by Rockstrom et al. (2009) illustrated that human societies overshoot several planetary boundaries. In a more recent publication, a similar approach was used to show that societies neither perform well on social indicators (Rockström et al., 2023).

To create more sustainable societies the United Nations developed the Sustainable Development Goals (SDGs), which were adopted in 2015. The SDGs are clustered into 17 overarching goals and contain 169 targets to create sustainable societies. In a recent progress report, it has been highlighted that we are not on track to reach the SDGs by 2030.

“It's time to sound the alarm. At the mid-way point on our way to 2030, the SDGs are in deep trouble. A preliminary assessment of the roughly 140 targets with data show only about 12% are on track; close to half, though showing progress, are moderately or severely off track and some 30% have either seen no movement or regressed below the 2015 baseline” (United Nations, 2023).

The latest IPCC report similarly shows that human societies are not on track to reach the Paris Agreement, which requires limiting temperature increase to 1,5°C. The IPCC warns that the window to take action is limited and that urgent and decisive action is needed (Lee & Romero, 2023).

Transition studies provide frameworks to understand past transitions and to hypothesize about how future transitions could unfold (Asquith et al., 2018; Schlaile & Urmetzer, 2021; Scoones et al., 2020; Sovacool & Hess, 2017). There are many different conceptions such as socio-technical transition theory (Frank W. Geels, 2002), socio-ecological transition theory (Gunderson & Holling, 2002), socio-institutional (Loorbach, Frantzeskaki, & Avelino, 2017) or socio-economic transition theory (Kemp, Pel, Scholl, & Boons, 2022), transition pathways (Ely, 2021b), the three horizons (Sharpe, Hodgson, Leicester, Lyon, & Fazey, 2016), etc. Many transition concepts have developed since the beginning of the 21<sup>st</sup> century. However, transition thinking predates the 21<sup>st</sup> century and can be connected to the sustainable development discourse (Schlaile & Urmetzer, 2021). Thus, the field of transition studies is part of development studies (Escobar, 2015).

The connection between the (sustainable) development debate and transition studies is illustrated by the history of the SDGs and its founding document. The SDGs are the successor of the Millennium Development Goals (MDGs), which mostly targeted the *development* of the *Global South* (United Nations, 2015, p. 5f.). The resolution that enacted the SDGs is titled *Transforming our world: the 2030 Agenda for Sustainable Development*. The notion of transformation is thus central to the SDGs. Understandably so, some projects exploring transitions use the SDGs as a starting point (Ely, 2021b).

The development debate is based on *Western* concepts of progress (Schöneberg & Häckl, 2020). What progress entails and how to measure it, is based on *Western* ideas. Nations should transform from rural to industrialized. This pathway includes modernization and the use of novel technologies, the installation of liberal market economies, and a certain annual GDP growth (Schmelzer, 2017). A famous framework that captures this development pathway is Rostow's (1969) *Stages of Economic Growth* (Foster-Carter, 1976). In his book, Rostow (1969) discussed the development steps starting from a traditional society and culminating in a society coined by high mass consumption. Rostow (1969) proposed that development and progress are achieved through industrialization, thus technological advancement (Mokyr,

2005) and economic growth (Schmelzer, 2015). Despite the criticism of Rostow's work his ideas and the notion of modernization as the path towards development and progress have not lost relevance (Solivetti, 2005).

The economic growth narrative is intricately linked to the development narrative (Schmelzer, 2017). Development and progress are not only linked to the notion of economic growth but also to the adoption of novel technology and continuous investment in technologies (Rosenberg, 1974). As Mokyr (2005) puts it: "Technology is knowledge. Knowledge [...] is at the core of modern economic growth, [...]." Due to the relevance of technology for economic growth and development, there are several scientific studies investigating the connection between science, technology, and economic growth (Pakes & Sokoloff, 1996; Rosenberg, 1974). Furthermore, research is dedicated to studying the conditions supporting the diffusion of innovations (Griliches, 1957; Rogers, 1983). The work of Rogers (1983), first published in 1962 (*The Diffusion of Innovation*), continues to influence studies about the diffusion of innovation (Alexander & Kent, 2021; Palm, 2022; Tabrizian, 2019).

Within the current economic system, it is argued that economic growth is needed to create the necessary savings to invest in new technology. That technology helps to increase the efficiency of processes, which helps to maintain and/or increase profits and thus invest in new technologies. Thus, the nexus between economic growth and technology creates a virtuous circle. In terms of *development*, it was technologies and modernization that freed up workforce (from agricultural activities) and made industrialization possible. Thus, questioning economic growth means questioning progress and well-being. Likewise, questioning technology means questioning progress and well-being. Despite the success of the *Western* path to progress, in the 1960s negative side-effects of this *development* path became apparent.

Rogers' (1983) book on the *Diffusion of Innovation* does not only discuss the conditions for technology uptake. He also reflects on a discourse that started as a response to the negative side effects of industrialization. Rogers (1983) argues that a paradigm shift is needed. Though he does not refer to a technological paradigm shift. Rather he criticizes the Eurocentric perspective on *development* as well as the blind focus on economic growth. Economic growth criticism started in the late 1960s. A landmark publication was the well-known *Limits to Growth* report published in 1972 (Meadows, 2010). Another example is Schumacher's *Small Is Beautiful: A Study of Economics As If People Mattered*, published in 1973 (Schumacher, 1973). Already in 1966 Boulding (1966) published his paper about the planet Earth as a spaceship criticizing people's but especially economists' inability to adjust to the fact that humans have to get by a limited amount of resources.

Since some environmental and social problems could be solved (at least temporarily), the environmental movements lost traction. The arguments brought forth by proponents of the technocentric perspective got support through successes in some areas. The Green Revolution provided more food to developing countries, and it seemed like the war on hunger was won (Paddock, 1970; Wharton, 1969). The energy shortage experienced in the 1970s was over due to the discovery and exploitation of new oil fields (Hall & Day, 2009).

Technological innovation has not only become the motor of economic growth but also a means to overcome resource shortages (Solow, 1974). Further, new technologies are used to solve problems that other technologies have caused (Fawzy, Osman, Doran, & Rooney, 2020; Freebairn, 1963). This might lead to the conclusion that environmental degradation can be

accepted since new technologies will eventually take care of it. With continuous economic growth and continuous resources invested in innovations, at some point, environmental degradation will diminish. The Environmental Kuznets (EK) curve captures this idea. The KC curve supports the idea of decoupling environmental burdens from economic activity, whereas decoupling is facilitated through innovation, such as clean technology. However, neither an EK curve pattern (Kaya Kanlı & Küçükefe, 2023) nor absolute decoupling could be attested (Haberl et al., 2020; Hickel & Kallis, 2020). Despite this evidence, trust in technology to facilitate sustainable development seems not to diminish.

Thus, the discourse that started in the 1960s is an ongoing one. It is a discourse between technocratic and ecocentric worldviews (Marletto, Franceschini, Ortolani, & Sillig, 2016). It is the discourse about weak and strong sustainability (Beckerman, 1995; Daly, 1995), the discourse between environmental and ecological economists. It is about discount rates, the incommensurability of capitals, the ways to measure and define well-being, or the monetarization of nature (Biely, 2014). It is about keeping the current economic system or replacing it with another one. It is about moving to a post-growth society or remaining stuck in a system that is based on unlimited (green) growth facilitated by technological advancements.

Mapping out different approaches to sustainable development, Marletto et al. (2016) distinguished between status quo and transformative approaches, whereat technocentric ones belong to the former and ecocentric ones to the latter. As pointed out above, the sustainability transition discourse is a continuation of the sustainable development discourse. Similar to the development discourse one can identify a technocentric and an ecocentric approach to transformation within transition studies. These two are represented by socio-technical and socio-ecological transition theory.

The work of Thomas Kuhn provides insights into paradigm changes within science. Socio-technical and socio-ecological transition theory can be understood as two transition theories based on different paradigms. To expand on this, the next section introduces the work of Thomas Kuhn. Further, the division into two different paradigms, marked by the institutionalization of the respective research streams, is outlined. Thereafter the dominance of one of the research streams within sustainability transition literature is illustrated. The next section explores how the two research streams break or continue with the dominant paradigm. The paper closes with a short discussion and the conclusion that the socio-technical transition theory fails to break with technocentric and growth-focused approaches to progress and development.

## 2. Kuhn's scientific revolutions

Kuhn's (2012) book *The Structure of Scientific Revolutions* is about paradigm changes within scientific disciplines. Science and society are connected. Scientific knowledge enters society in many ways, such as consultancy, education (Halbe, Adamowski, & Pahl-Wostl, 2015; Lozano, Lozano, Mulder, Huisingh, & Waas, 2013), or policy-making (Blythe et al., 2018; Pregernig, 2014; Schlüter et al., 2022). Thus, the way scientists frame problems and the solutions that scientists suggest influence societies (Blythe et al., 2018; Pregernig, 2014). "Researchers play an important role in framing sustainability transformations, and this calls for reflexivity, given the power they hold as actors within them" (Ely, 2021a, p. 41). Accordingly, scientists are not detached from society but take active roles (Kurzman & Owens, 2002). Transition literature suggests that scientists should seek an even more active role in

transformative processes (Wittmayer & Schöpke, 2014). An example of the influence of scientists is the development of the GDP metric, which was linked to scientific endeavors (Lepenies, 2016; Schmelzer, 2015). Similarly, endeavors to provide alternative metrics (such as GPI) influence societies (Berik, 2018; Le Cacheux & Laurent, 2015).

Given the fact that we are not achieving our SDGs and that we are continuing to overshoot planetary boundaries, it can be argued the scientific fields dealing with sustainable development and sustainability transitions (including economics) need a paradigm shift just as much as our societies need such a paradigm shift. Breaking with how scientists frame sustainability problems could help to stop perpetuating narratives that are part of the problem.

Thomas Kuhn's (2012) work gives insights into paradigm shifts within science. He does not only outline how such shifts come about but also why they are lengthy and difficult processes. The discussion about paradigm changes related to sustainable development and sustainability transition discourse is not new. Already Rogers (1983), who wrote about *The Diffusion of Innovation*, reflected on the resonance of the diffusion discourse with the development paradigm and the echo chambers within scientific disciplines. Pertaining to the latter, he referred to the insights of Thomas Kuhn.

„During the past twenty years or so, diffusion research has grown to be widely recognized, applied, and admired, but it has also been subjected to constructive and destructive criticism. This criticism is due in large part to the stereotyped and limited ways in which most diffusion scholars have come to define the scope and method of their field of study. Once diffusion researchers came to represent an "invisible college,"\* they began to limit unnecessarily the ways in which they went about studying the diffusion of innovations. Such standardization of approaches has, especially in the past decade, begun to constrain the intellectual progress of diffusion research" (Rogers, 1983, p. xvii).

In the footnote (marked by the asterisk), Rogers referred to the work of Kuhn, explaining that the "invisible college is an informal network of researchers who form around an intellectual paradigm [...]" (ibid.). In fact, Rogers dedicated a whole section to the topic of paradigms and the invisible colleges (Rogers, 1983, p. 42ff.). Connected to this discussion about paradigms is Rogers' reflection on the diffusion studies' contribution to the at the time prevalent development paradigm. Rogers concluded that the elements of the development paradigm fit the classical diffusion model quite well. These elements, among others, are a focus on economic growth, industrialization, and technology. As pointed out above, Rogers called for a paradigm shift. Not merely for a technological paradigm shift, but a shift away from growthism, trickle-down rhetoric, and Eurocentric development views (Rogers, 1983, p. 120ff.).

Others have used Kuhn's work as well to discuss paradigm changes in the context of the sustainable development discourse<sup>1</sup>. Foster-Carter (1976) used Kuhn's ideas to discuss conflicting paradigms within development studies. He used it to confront the prevalent development paradigm, based on Rostow's (1969) *Stages of Economic Growth*, with neo-Marxian ideas of development. Williams and McNeill (2005) used Kuhn's work to describe the

---

<sup>1</sup> For an account about the limitations of Kuhn's work in context of social sciences see Foster-Carter (1976).

paradigm shift within economics and its relation to development thought. Thus, a shift from growth-centered technocentric development towards an ecocentric perspective.

Kuhn (2012) described scientific activities as puzzle-solving. This puzzle-solving activity is called normal science. Puzzle-solving does not aim to discover real novelty. That is since the result of the puzzle is predetermined by the paradigm. One could say that the paradigm is the picture on the box of the puzzle. If scientists encounter anomalies, the paradigm is not automatically scrutinized, but the anomalies are made fit the paradigm. That is why paradigm changes within science take a long time. There are mechanisms that protect a discipline from a paradigm change. These are institutional and psychological mechanisms. For example, Kuhn (2012) referred to confirmation bias. Examples are scientists who, being confronted with an anomaly, rather question their experimental setup than the paradigm. Or they search for logical explanations that are in line with the paradigm, rather than questioning the paradigm. Furthermore, Kuhn (2012) referred to power structures. As indicated by Rogers (1983), scientists are part of an ingroup, which is following a specific paradigm. The group tries to protect its existence by protecting the paradigm. Examples are journals reluctant to publish research that challenges the paradigm the journal represents.

Despite these protective mechanisms at some point, paradigms change. That happens when too many anomalies have been found and a new paradigm is better at explaining these anomalies. Kuhn (2012) described different phases as well as the characteristics of these phases. For example, a prevalent paradigm is usually institutionalized. The paradigm is represented by journals, scientific groups, and curricula. Evolving new paradigms strive for this institutionalization as well. Proponents of an alternative paradigm need to establish their own institutions because they are not heard in the institutions representing the dominant paradigm. Thus, new journals and new groups can be an indication of alternative paradigms forming. The evolution of a new paradigm is also signaled through books. That is because the foundation needs to be built and hence scientific papers do not provide enough space to lay out this foundation.

The paradigm change does not mean that we get more evidence than we had before, but that we see the evidence we have in different ways. The different way of seeing the world is incommensurable with the previous way of seeing the world. If they were not a new paradigm was not necessary to form as it could be an extension of the old. An example is GDP. Some see it as a metric to measure well-being, others as a metric to measure material throughput (thus rather degradation) (Daly, 1996). It is the same set of data, interpreted in different ways. The different interpretation stems from different worldviews through which researchers approach the dataset.

### 2.1. Socio-technical and socio-ecological paradigm

Within this paper, two different paradigms within transition studies are used to illustrate that the discourse within sustainable development studies is continuing within transition studies. The paradigms building the foundation for socio-technical and socio-ecological transition theory present a continuation of the technocentric versus ecocentric worldview discourse.

Following Kuhn's (2012) work there are clear indicators for the formation of distinct research avenues that are based on specific paradigms. These indicators are related to the institutionalization of distinct research avenues. Socio-ecological and socio-technical approaches to sustainability transition are represented in distinct groups (Sustainability Transitions Research Network (STRN) and Future Earth), different journals (Environmental

Innovation and Societal Transitions (EIST) and Ecology and Society), different conferences (International Sustainability Transitions Conference (IST) and Transformations) as well as different books providing the basic foundations of the respective paradigm (for example: Grin, Rotmans, and Schot (2010) and Gunderson and Holling (2002)).

The topics within the representative journals indicate a clear dominance of one of the two paradigms. A Scopus keyword search limited to title, abstract, and keywords within the two main journals shows that EIST has 141 articles with the keyword “socio-tech\*” and only 4 with the keyword “socio-ecol\*”. In Ecology and Society, 20 articles have the keyword “socio-ecol\*” and 8 the keyword “socio-tech\*”. This pattern indicates what Kuhn (2012) discussed in terms of a journal’s potential reluctance to publish ideas that challenge the paradigm represented by the respective journal.

There are many similarities between the socio-ecological transition theory (the adaptive cycle) and the socio-technical transition theory (using the MLP). For example, both work on different scales, whereas each scale has certain characteristics (e.g. stability). Both discuss the problem of lock-ins created by the rigidity of the current system. Socio-technical theory uses the notion of the socio-technical landscape. A similar approach can be found in resilience theory, where resilience is explained using the topography of a landscape (Walker, Holling, Carpenter, & Kinzig, 2004). Socio-ecological transition theory uses resilience thinking as well as the notion of lock-ins. However, resilience is not only determined by technological artifacts but by the natural system as well. Other similarities are that both refer to Schumpeter’s idea of creative destruction, both look at the role of technology<sup>2</sup> in change processes and both use the concept of complex adaptive systems.

Despite these similarities, I argue that the different transition theories cannot be combined. Even if one might be tempted to see how they can be integrated (Frank W. Geels, 2010; Nilsen, 2010). They cannot be combined because they develop out of different worldviews, one that understands nature to be an external factor and one that does not. In line with Kuhn’s (2012) argumentation, one could say that if socio-technical and socio-ecological transition theories were the same, they would not need different institutions. One could easily integrate publications focusing on human-nature interactions within journals that frame the world as a socio-technical system. The split between socio-technical and socio-ecological transition theory is similar to the split between environmental economics and ecological economics (Biely, 2014). These two follow different pre-analytical visions, as Daly (1996) calls it. The different pre-analytical visions are famously illustrated by the weak and strong sustainability illustrations (see Figure 1). And it is reflected by ecological economists taking the economic system out of its vacuum and placing it within the natural environment (R. Costanza, Hart, Posner, & Talberth, 2009).

---

<sup>2</sup> This is obvious for socio-technical transition theory. But socio-ecological theory too looks at the role of technology. For Gunderson and Holling (2002) the use of technology is one of four factors that explains differences between the natural and the social system and why socio-ecological systems can change faster than natural systems. These factors can also explain why systems become maladaptive and hence to not change.

a)

b)

Figure 1: a) weak sustainability, b) strong sustainability. Weak sustainability depicts sustainability as the overlap between social, economic, and environmental spheres. Strong sustainability depicts the economy embedded within the social system, which is embedded in the natural system.

### 3. The dominance of theories

Analog to the views of scientific pluralism (Ludwig & Ruphy, 2021) it can be stated that scientific inquiry and knowledge production profit from diversity. A diversity of concepts, theories, or approaches allows scientists to reflect and thus further develop the field (Bernard & Cooperdock, 2018; Kuhn, 2012). A lack of diversity may create an ontological and epistemological lock-in, where scientists get trapped in an echo chamber (Chappin & Ligtoet, 2014; Unerman, 2020), or an invisible college, as Rogers (1983) called it. A diversity of transition approaches can “safeguard against the appropriation of the term [transition or transformation] by any single framing or perspective” (Blythe et al., 2018). And as Ely (2021a, p. 41) states: “Working across and beyond different disciplines alerts us to the fact that sustainability is subject to very different and conflicting understandings.” To investigate the diversity of concepts within sustainability transition literature, a systematic literature search was conducted.

Using the search key "sustainability transition" limited to title, abstract, and keywords on Scopus rendered 2442 scientific publications. To explore this body of literature, the keywords were analyzed. Among the 20 most used keywords only socio-technical transition theory and transition management can be found (see Table 1). Concepts that focus on other aspects of sustainability transitions or frame systems in different ways could be found in ranks 29 and 33 (resilience and socio-ecological). Other keywords related to socio-ecological framings were ranked even further down the list. This illustrates the dominance of socio-technical transition theory within sustainability transition literature. It shows that the main analytical frame for sustainability transitions is the Multi-Level Perspective (MLP) and that systems are predominantly framed as socio-technical.

Table 1: Keyword frequency

Keyword	Count
Sustainability transition	995
Sustainability	229
Transition	126
Multi-level perspective	105
Sustainable development	69
Circular economy	60
Socio-technical transition	58

Transition management	57
Energy transition	55
Governance	47
Renewable energy	41
Climate change	37
Innovation	37
Socio-technical systems	37
Transformation	35
Agency	32
Transdisciplinarity	32
Strategic niche management	30
Policy mix	27
Social innovation	27
Agroecology	24
Urban sustainability transition	23
China	22
Cities	21
Bioeconomy	21
Policy	21
Social learning	21

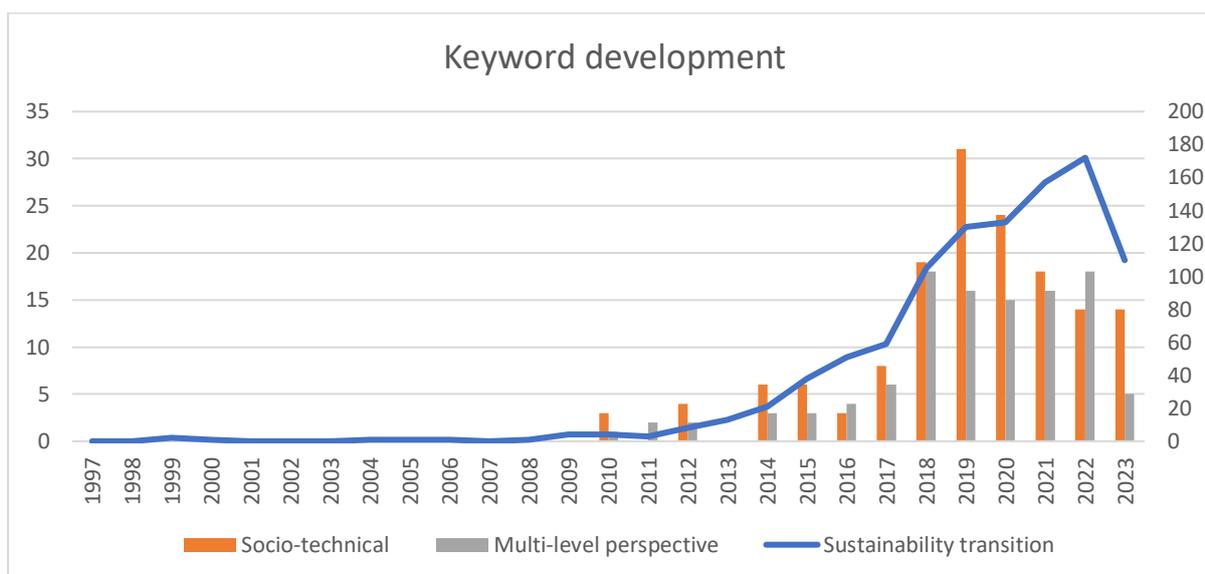


Figure 2: evolution of keyword use. **Socio-technical** is the sum of the following keywords: Socio-technical, Socio-technical analysis, Socio-technical change, Socio-technical configuration analysis, Socio-technical configurations Socio-technical experiments, socio-technical imaginaries, socio-technical innovation, socio-technical landscape, socio-technical levers, socio-technical niches, Socio-technical pathways, Socio-technical regimes, Socio-technical scenario, socio-technical systems, socio-technical systems analysis, socio-technical transition, socio-technical transition theory. **Multi-level perspective** is the sum of the following keywords: Multi-level perspective, Multi-level perspective of sustainability transition, multi-level perspective on socio-technical transition, Multi-level perspective on sustainability transition, multi-level perspective theory. The **sustainability transition** keyword (right axis) is a combination of sustainability transition and sustainability transformation.

Over the years the socio-technical transition theory has become the dominant sustainability transition theory. Figure 2 shows the keyword development between 1997 and 2023. It illustrates only the keywords “socio-technical” and “multi-level perspective” along with “sustainability transition”. The number of keywords per year related to socio-ecology is too small to be visible on this chart. The dominance of the socio-technical transition theory might reflect the general dominance of this worldview among scientists dealing with sustainability transition questions. The dominance might be further pushed by books titled *Transitions to*

*Sustainable Development* (Grin et al., 2010), which only cover socio-technical transition theory and transition management. Similarly, in a review of transition theories, Markard, Raven, and Truffer (2012) only include theories related to technological change. The main theories mentioned are Technological Innovation Systems, Multi-Level Perspective, Strategic Niche Management, and Transition Management. The less well-versed reader might get the impression that socio-technical transition theory is indeed THE transition theory, which is, of course, a misrepresentation, as there are many transition theories (Asquith et al., 2018; Schlaile & Urmetzer, 2021). Arguably, socio-technical transition theory provides a good analytical framework to understand technological change (Frank W. Geels, 2006) and lock-ins (Ford & Newell, 2021). Though, the question is whether it should implicitly be framed as THE sustainability transition theory and whether it should be used for transitions that are not about technology (Vandeventer, Cattaneo, & Zografos, 2019).

Education is one of the ways paradigms are established and maintained (Kuhn, 2012). Not only is education a means to recruit new scientists to follow the taught paradigm. It is also a means to connect science with the real world. Future politicians, CEOs, and employees are taught a specific worldview (Jickling, 2016). Without a diversity of theories provided to students, they might blindly take over the paradigm they were taught. Examples of biased representations of transition studies are provided by Markard et al. (2012) as well as Grin et al. (2010). In both publications, the authors fall short of mentioning sustainability transition approaches that do not focus on technology. Yet the titles of the documents and the text give the impression that the content captures sustainability transitions literature in its entirety. An updated version of the Markard et al. (2012) paper similarly falls short of mentioning sustainability approaches that capture human-nature connections (such as socio-ecological thinking) (Köhler et al., 2019).

The Markard et al. (2012) paper not only *captures* transition studies but also the institutionalization of these studies through the launch of EIST and the formation of STRN. Thus, the publication serves to demarcate the field. Clearly, socio-ecological views are not part of it. From a Kuhnian perspective, one can see how socio-technical transition theory formed as a distinct paradigm within transition studies that has managed to become the predominant one.

#### 4. Socio-technical transition theory

Socio-technical transition theory gained momentum through the work of Frank Geels (F. W. Geels, 2002)<sup>3</sup>. His dissertation is titled: *Understanding the Dynamics of Technological Transitions: A Co-evolutionary and Socio-technical Analysis*. His first scientific paper capturing his Ph.D. thesis is titled: *Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study* (Frank W. Geels, 2002). The headings indicate that Geels approaches processes of social change through a technological lens. That technology lens is also emphasized in the abstract of his 2002 paper: “This paper addresses the question of how technological transition (TT) comes about?” The social sphere is added to understand technological change, as he outlines that the mainstreaming of technology requires “changes in user practices, regulations, industrial networks infrastructure, and symbolic meaning or culture” (Frank W. Geels, 2002). Thus, Geels’ work falls in the sociological tradition of diffusion

---

<sup>3</sup> The multi-level perspective as well as socio-technical transition were already earlier discussed by René Kemp, Arie Rip, or Johan Schott. The latter two were Frank Geels PhD promotors.

of innovation research investigating the connection between technological innovations and society (Rogers, 1983, p. 50)<sup>4</sup>

Although socio-technical transition theory might be framed as sustainability transition theory, it has been developed to understand technological transitions. Arguably the societal aspects of technological transitions have been further explored since the 2002 paper. Using insights from sociology, Frank W. Geels (2004) outlined in more detail how technological changes are connected to society. The Multi-Level Perspective<sup>5</sup> has also been combined with behavioral science (Keller, Sahakian, & Hirt, 2022), research on power (Avelino, 2017; Frank W. Geels, 2014), or agency (F. W. Geels, 2020). Some have also extended the MLP to integrate the role of individuals (F. W. Geels, 2020; Göpel, 2016).

With socio-technical transition theory being the main sustainability transition theory it has found wide applications such as for the green economy (Gibbs & O'Neill, 2014), the circular economy (Mathur, Gregory, & Imran, 2022), the protein transition (Bulah, Tziva, Bidmon, & Hekkert, 2023), or the energy transition (Prados, Iglesias-Pascual, & Barral, 2022). Though focusing on technological change (and its connections to society) does not address the underlying problems that caused the sustainability challenges humanity is facing (Ruggeri & Garrido, 2021).

For example, an energy transition that is merely based on switching to renewables without considering resource limitations will lead to new problems (Watari et al., 2019). A transition toward a sustainable fashion industry might be inhibited in a system that requires economic growth (Dzhengiz, Haukkala, & Sahimaa, 2023). Accordingly, it can be questioned whether technological innovation *per se* leads to sustainable societies. Technological innovations do not address questions of resource access, or the distribution of burden and benefit. Technologies widely used today, have on the one hand contributed to the well-being of some share of the global population. Though, on the other hand, these technologies are devastating our planet (e.g. plastic: Bergmann et al., 2022; MacLeod, Arp, Tekman, & Jahnke, 2021). New technologies that aim to solve current problems are not free of negative environmental side effects (Marín & Goya, 2021; Watari et al., 2019). Thus, we remain with the points brought up by Boulding in 1966.

Technological innovation is for sure part of a sustainability transition, but there are many more topics that need to be addressed (Kates & Parris, 2003). One of these topics is whether an economic system that is based on continuous economic growth can create sustainable societies. Can an economy where the I in the IPAT equation is predominantly reduced through the T, create sustainable societies? As I have indicated above, evidence shows, that the Affluence variable needs to be addressed too (Common & Stagl, 2005). That though, calls for an alternative economic system where a reduction in consumption does not equate to recession and hardship.

Accordingly, many argue that a sustainability transition requires addressing worldviews and paradigms (such as economic growth) (Abson et al., 2017; Davelaar, 2021; Fischer & Riechers,

---

<sup>4</sup> At the time Rogers' wrote his book, economics was only categorized as a minor tradition of diffusion of technology studies. Given the significance of market mechanism within socio-technical transition theory and the fact that it is based on evolutionary economics, socio-technical transition theory is also part of the the economic tradition.

<sup>5</sup> This is the analytical frame used to understand the interactions between technology markets and society on three different scales.

2019; Woiwode et al., 2021). Some have used the MLP to explore a worldview shift. Göpel's (2016) work on *The Great Mindshift*, used the MLP to illustrate the worldview shift within the transition process. Similarly, Naberhaus et al. (2011) theorized about worldview changes using the MLP. Thus, the MLP might be a tool that can be used to challenge the current development narrative. Though these authors mostly seem to use the MLP because of its ability to illustrate different scales. The MLP is then no longer used to investigate technological innovation. One also remains to wonder what the vehicle of change in these examples might be. The MLP builds on market forces. It is difficult to imagine how market forces lead to a mindset change (though enlightening books are exchanged within the market system). The idea of market forces being the vehicle of change resembles the idea of a Trojan horse, where the current is destroyed from within. Even if Vandeventer et al. (2019) used the MLP to explain the growth of the degrowth movement it remains unclear what the vehicle of a system-wider worldview change would be.

With its focus on technological transition, it seems that socio-technical transition theory perpetuates the development narrative and the separation of humans from nature. Specifically, the notion of the landscape within the MLP supports this assumption. Environmental factors are captured in the landscape (amongst others). The landscape is framed as an external factor that can hardly be influenced by the regime or the niche. By defining the environment as an external factor<sup>6</sup>, the MLP frame has parallels to neoliberal views. There too environmental factors are external (Robert Costanza et al., 1998). As Boulding (1966) discussed in 1966, the exclusion of the environment leads to environmental degradation.

Within socio-technical transition theory, the detachment between nature and societies is further supported by proposing that humans do not live in a biotope but in a technotope (Frank W. Geels & Schot, 2007). The idea of the technotope perpetuates the worldview that technology is the main factor influencing our lives. It perpetuates the neglect of the material base that is necessary for all that is, for the natural buffer systems that have allowed humans to live in a stable environment. It is humans' neglect of that reality that jeopardizes the natural buffer systems and resource abundance.

With its focus on technological transition, one needs to question whether socio-technical transition theory can help us to understand how we can change our economic system; how we can abandon growthism. Since technological progress and economic growth are tied together one must also ask whether the socio-technical transition theory is perpetuating the progress and development narratives born in the late 1940s (Schmelzer, 2017). From a Kuhnian perspective, socio-technical transition theory represents puzzle-solving within normal science.

## 5. Socio-ecological transition theory

A transition theory that acknowledges the fact that humans are living within a biotope is the socio-ecological transition theory. In *Panarchy*, Gunderson and Holling (2002) outlined the phases of change captured by the adaptive cycle. The adaptive cycle itself was born out of the analysis of natural change processes. Gunderson and Holling (2002) used the adaptive cycle

---

<sup>6</sup> Without discussing this further it might also give the impression that humans might not have the ability to do something about climate change. Therefore, it limits the agency of humans for problems human societies have created.

to explain change processes of socio-ecological systems. I do not want to expand on the adaptive cycle itself and how the process of change is described as this is not the purpose of this article. The main point is that socio-ecological thinking frames the system as socio-ecological. Within *Panarchy*, technologies are presented as relevant factors within transition processes as well (Gunderson & Holling, 2002). However, instead of framing technology as the solution to sustainability issues, the downsides of technology are highlighted. The downsides relate to the notion of socio-technical landscapes used in socio-technical transition theory (Frank W. Geels & Schot, 2007). The lock-ins created by technologies stem from human's inability to fully understand the world's complexity. Thus, solutions only address a current problem without taking account of (or ignoring) side effects across scales (time and space). That has the effect that humans are trapped in a vicious cycle where they constantly have to solve the problem created by the solution they have applied to another problem (Béné, 2022).

I have already indicated that the way lock-ins are described through the notion of socio-technical landscapes strikingly resembles the illustration of resilience by Walker et al. (2004). Gunderson and Holling (2002) reflect on two different approaches to resilience. One focuses on efficiency, the other on sustenance. The former is the technocentric approach to resilience where one wants to increase control, thus reducing variability. The other focuses on diversity. This is based on an ecological understanding of resilience where diversity and redundancies create the buffers for a system to remain stable over long periods of time. An ecological approach to resilience calls for maintaining the niche. It does not want to upscale the niche as this would rid the system of necessary buffer capacity.

An ecological worldview leads to completely different problem framings and thus the solutions one would suggest are different. A socio-ecological view does not neglect the role of technology, but it places technology within a socio-ecological context. It would turn economic thinking on its head asking for where we need to create redundancies (thus *inefficiency*) to increase the resilience and thus the adaptability of the system. Such thought might conflict with economic theory that is based on the generation of profit (to increase saving to invest in new technologies that can increase efficiencies so that we can create more profit, etc.). Thus socio-ecological thinking would call for breaking with the currently dominant growth paradigm and technocentric views. Socio-ecology, framing the world differently, provides alternative solutions for the anomalies we have been observing since the 1960s.

## 6. Discussion and Conclusion

As argued in transition literature, scientists may take a more active role in transition studies. Though scientists are influencing the world, whether or not they are working with stakeholders. The way we frame problems and the solutions we offer make a difference. In the book *Transformative Pathways to Sustainability: Learning Across Disciplines, Cultures and Contexts*, Ely (2021a, p. 38) discussed how academia itself contributes to stagnancy. The authors refer to the article by Blythe et al. (2018) who discussed *The Dark Side of Transformations*. One of these is that the academic discourse supports perpetuating the status quo by using a new label instead of really changing something. One such example used by Blythe et al. (2018) is green growth or the green economy; a matter also discussed in more detail by others (R. T. V. Hamilton & Ramcilovic-Suominen, 2023; Wanner, 2015). The

perpetuation of the status quo is also discussed by Leach, Stirling, and Scoones (2010), who highlight the aspect of dominance (see also R. T. V. Hamilton & Ramcilovic-Suominen, 2023).

“Particular narratives are produced by particular actors and co-construct particular pathways of response. Some are dominant and; shaped by powerful institutions and substantial financial backing – these are the ‘motorways’ that channel current mainstream environments and development efforts. But these can often obscure and overrun alternatives; the smaller by-ways and brush paths that define and respond to different goals, values and forms of knowledge” (Leach et al., 2010, p. 5).

I have indicated that environmental and social problems related to economic activity are not a new phenomenon. Nevertheless, questioning growthism and technocentric views is difficult. Proponents of these views have managed to provide explanations that make the anomalies (sustainability challenges) fit the paradigm. The idea of weak sustainability is the pushback of economists showing that the anomalies do not invalidate their assumptions (K. Hamilton, 1995; Solow, 1974). Thus, the concept of weak sustainability needed to be invented to integrate the anomalies within the economic growth paradigm. Increasing inequality has been matched with the Kuznets curve and trickle-down rhetoric. Or the blame was put on government mismanagement rather than the market mechanism (Raffer & Singer, 2001). Environmental problems have been matched with the EK curve and ideas of decoupling. Or the blame was put on market failures (e.g., externalities, which interestingly then calls for an extension of the market mechanism).

The role of technology is key to defending the current economic system and it is central to the mainstream sustainability transition discourse. The economy has become green, circular, or bio. The role of technology to make this change happen is central. Though, these changes do not address the fundamental problems of our current economic system. Research indicates that a circular, bioeconomy needs to acknowledge planetary boundaries (Desing et al., 2020; Holden, Neill, Stout, O’Brien, & Morris, 2023; Ramcilovic-Suominen, Kröger, & Dressler, 2022). Accordingly, we need to shift from viewing society as being embedded in a technotope, to one embedded in a biotope. As Borrello, Cembalo, and D’Amico (2023) put it:

“Based on the power that concepts as the Circular Economy and the Anthropocene have had in the recent past, a future step to develop an ecological worldview across society, and nourish individual identities deeply committed with the preservation of natural ecosystems, is working on narratives based on the notion of human-nature interdependence.”

As long as suggested transformations focus on technology and market mechanisms they will fall short of solving underlying problems (Pungas, 2023). Using practical examples, Leach et al. (2010) illustrated how closed-down technocratic worldviews equate to the application of a reductionist frame that brings forth ill-suited *solutions*. Similarly, Leeuwis, Boogaard, and Atta-Krah (2021) showed how interventions in the food system do not change the fundamental problems within that system. They argued that the interventions fail to address issues of inequality because they do not challenge but rather align with the current paradigm. To tackle inequality, they suggested reverting to alternative approaches that challenge the dominant paradigm. Specifically, they refer to approaches that “[...] start from ecological principles of community and environmental sustainability” (ibid.).

Analyzing transformations in food systems Béné (2022) stated that one problem with technology-based transitions is that they rely on market forces. A primary condition for a

technology to survive and to be mainstreamed is the technologies “economic viability not its potential future societal benefits” (Béné, 2022). He reflected on an article by Herrero et al. (2020), who selected 75 innovations that could transform the food system. Béné (2022) highlighted that these 75 innovations are a wish list, but that due to the complexity of the transition process, it cannot be assured that these technologies really succeed. “Symbolistically, they [scientists] replace the ‘invisible hand’ by a visible one in an attempt to steer innovations towards sustainability. But the market, left alone, is blind to sustainability” (Béné, 2022). Arguably, the same is true for technologies. Technologies are blind to sustainability. With every technology, we are faced with burden and benefit questions, with questions about sustainable scales, etc. To consider these questions we not only have to understand the social dynamics permitting or blocking technology mainstreaming. We not only have to understand the positive and negative consequences of technology upscaling on the social system. We also must understand that the social system sits within an ecosphere. Thus, the solutions we apply and how we apply them depend on our worldview.

Socio-technical transition theory focuses on technology transitions, and it relies on the market mechanism as a vehicle of change. Potentially most importantly it describes society as being placed within a technotope, further perpetuating the narrative of societies being detached from nature. It perpetuates the narrative of progress that was born in the late 1940s. Thus, instead of providing real novelty, it remains in the realm of normal science. Similar to the analysis of Marletto et al. (2016), one has to conclude that socio-technical transition theory is a sustainability transition approach that argues that through business-as-usual mechanisms sustainability can be achieved. As I have outlined scientists have contributed to making anomalies fit into the mainstream growth paradigm. Socio-technical transition theory does not break with this endeavor.

## References:

- Abson, D. J., Fischer, J., Leventon, J., Newig, J., Schomerus, T., Vilsmaier, U., . . . Lang, D. J. (2017). Leverage points for sustainability transformation. *Ambio*, 46(1), 30-39. doi:10.1007/s13280-016-0800-y
- Alexander, B., & Kent, A. (2021). Tracking technology diffusion in-store: a fashion retail perspective. *International Journal of Retail & Distribution Management*, 49(10), 1369-1390. doi:10.1108/IJRDM-05-2020-0191
- Asquith, M., Backhaus, J., Geels, F., Golland, A., Hof, A., Kemp, R., . . . Weaver, P. (2018). *Perspectives on transitions to sustainability*. Retrieved from blob:<https://www.eea.europa.eu/bd16ce9d-19e4-4243-8c7d-39182dbcfceb>
- Avelino, F. (2017). Power in Sustainability Transitions: Analysing power and (dis)empowerment in transformative change towards sustainability. *Environmental Policy and Governance*, 27(6), 505-520. doi:10.1002/eet.1777
- Beckerman, W. (1995). How Would you Like your 'Sustainability', Sir? Weak or Strong? A Reply to my Critics. *Environmental Values*, 4(2), 169-179. Retrieved from <http://www.jstor.org/stable/30301474>
- Béné, C. (2022). Why the Great Food Transformation may not happen – A deep-dive into our food systems’ political economy, controversies and politics of evidence. *World Development*, 154, 105881. doi:<https://doi.org/10.1016/j.worlddev.2022.105881>
- Bergmann, M., Collard, F., Fabres, J., Gabrielsen, G. W., Provencher, J. F., Rochman, C. M., . . . Tekman, M. B. (2022). Plastic pollution in the Arctic. *Nature Reviews Earth & Environment*, 3(5), 323-337. doi:10.1038/s43017-022-00279-8

- Berik, G. (2018). *Toward more inclusive measures of economic well-being: Debates and practices*. Retrieved from [https://www.ilo.org/wcmsp5/groups/public/---dgreports/--cabinet/documents/publication/wcms\\_649127.pdf](https://www.ilo.org/wcmsp5/groups/public/---dgreports/--cabinet/documents/publication/wcms_649127.pdf)
- Bernard, R. E., & Cooperdock, E. H. G. (2018). No progress on diversity in 40 years. *Nature Geoscience*, 11(5), 292-295. doi:10.1038/s41561-018-0116-6
- Biely, K. (2014). *Environmental and Ecological Economics: Two approaches in dealing with economy-environment interrelations and the case of the Economics of Land Degradation initiative*. (Magistra). Universität Wien, Vienna. Retrieved from [https://www.katharinabiely.com/files/ugd/e849da\\_baf573475ec64925b4a6ef3eefa\\_bc572.pdf](https://www.katharinabiely.com/files/ugd/e849da_baf573475ec64925b4a6ef3eefa_bc572.pdf)
- Blythe, J., Silver, J., Evans, L., Armitage, D., Bennett, N. J., Moore, M.-L., . . . Brown, K. (2018). The Dark Side of Transformation: Latent Risks in Contemporary Sustainability Discourse. *Antipode*, 50(5), 1206-1223. doi:<https://doi.org/10.1111/anti.12405>
- Borrello, M., Cembalo, L., & D'Amico, V. (2023). Narratives to revert overconsumption: human-nature interdependence and Circular Economy. *Agricultural and Food Economics*, 11(1), 19. doi:10.1186/s40100-023-00259-6
- Boulding, K. (1966). *The Economics of the Coming Spaceship Earth*,. Paper presented at the Resources for the Future Forum, Washington.
- Bulah, B. M., Tziva, M., Bidmon, C., & Hekkert, M. P. (2023). Incumbent entry modes and entry timing in sustainable niches: The plant-based protein transition in the United States, Netherlands, and United Kingdom. *Environmental Innovation and Societal Transitions*, 48, 100735. doi:<https://doi.org/10.1016/j.eist.2023.100735>
- Chappin, E. J. L., & Ligtvoet, A. (2014). Transition and transformation: A bibliometric analysis of two scientific networks researching socio-technical change. *Renewable and Sustainable Energy Reviews*, 30, 715-723. doi:<https://doi.org/10.1016/j.rser.2013.11.013>
- Common, M., & Stagl, S. (2005). *Ecological Economics: An Introduction*. Cambridge, New York, Melbourne, Cape Town, Singapore, Sao Paulo, Delhi, Mexico City: Cambridge University Press.
- Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., . . . van den Belt, M. (1998). The value of the world's ecosystem services and natural capital. *Ecological Economics*, 25(1), 3-15. doi:[https://doi.org/10.1016/S0921-8009\(98\)00020-2](https://doi.org/10.1016/S0921-8009(98)00020-2)
- Costanza, R., Hart, M., Posner, S., & Talberth, J. (2009). *Beyond GDP: The Need for New Measures of Progress*. Boston: Pardee Center for the Study of the Longer-Range Future.
- Daly, H. E. (1995). On Wilfred Beckerman's Critique of Sustainable Development. *Environmental Values*, 4(1), 49-55. Retrieved from <http://www.jstor.org/stable/30301392>
- Daly, H. E. (1996). *Beyond Growth: The Economics of Sustainable Development*. Boston: Beacon Press.
- Davelaar, D. (2021). Transformation for sustainability: a deep leverage points approach. *Sustainability Science*, 16(3), 727-747. doi:10.1007/s11625-020-00872-0
- Desing, H., Brunner, D., Takacs, F., Nahrath, S., Frankenberger, K., & Hirschier, R. (2020). A circular economy within the planetary boundaries: Towards a resource-based, systemic approach. *Resources, Conservation and Recycling*, 155, 104673. doi:<https://doi.org/10.1016/j.resconrec.2019.104673>

- Dzhengiz, T., Haukkala, T., & Sahimaa, O. (2023). (Un)Sustainable transitions towards fast and ultra-fast fashion. *Fashion and Textiles*, 10(1), 19. doi:10.1186/s40691-023-00337-9
- Ely, A. (2021a). Transformations. In A. Ely (Ed.), *Transformative Pathways to Sustainability: Learning Across Disciplines, Cultures and Contexts* (1st edition ed.): Routledge.
- Ely, A. (2021b). *Transformative Pathways to Sustainability: Learning Across Disciplines, Cultures and Contexts* (1st edition ed.): Routledge.
- Escobar, A. (2015). Degrowth, postdevelopment, and transitions: a preliminary conversation. *Sustainability Science*, 10(3), 451-462. doi:10.1007/s11625-015-0297-5
- Fawzy, S., Osman, A. I., Doran, J., & Rooney, D. W. (2020). Strategies for mitigation of climate change: a review. *Environmental Chemistry Letters*, 18(6), 2069-2094. doi:10.1007/s10311-020-01059-w
- Fischer, J., & Riechers, M. (2019). A leverage points perspective on sustainability. *People and Nature*, 1(1), 115-120. doi:<https://doi.org/10.1002/pan3.13>
- Ford, A., & Newell, P. (2021). Regime resistance and accommodation: Toward a neo-Gramscian perspective on energy transitions. *Energy Research & Social Science*, 79, 102163. doi:<https://doi.org/10.1016/j.erss.2021.102163>
- Foster-Carter, A. (1976). From Rostow to Gunder Frank: Conflicting paradigms in the analysis of underdevelopment. *World Development*, 4(3), 167-180. doi:[https://doi.org/10.1016/0305-750X\(76\)90025-5](https://doi.org/10.1016/0305-750X(76)90025-5)
- Freebairn, H. T. (1963). Removal of Toxic Gases in Smog with Metal Filters. *Journal of the Air Pollution Control Association*, 13(5), 218-219. doi:10.1080/00022470.1963.10468169
- Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, 31(8-9), 1257-1274. doi:[http://dx.doi.org/10.1016/S0048-7333\(02\)00062-8](http://dx.doi.org/10.1016/S0048-7333(02)00062-8)
- Geels, F. W. (2002). *Understanding the Dynamics of Technological Transitions, A Co-evolutionary and Socio-technical Analysis*. (Ph.D.). Twente University Press, Enschede, NL.
- Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy*, 33(6-7), 897-920. doi:<http://dx.doi.org/10.1016/j.respol.2004.01.015>
- Geels, F. W. (2006). Major system change through stepwise reconfiguration: A multi-level analysis of the transformation of American factory production (1850-1930). *Technology in Society*, 28(4), 445-476. doi:<http://dx.doi.org/10.1016/j.techsoc.2006.09.006>
- Geels, F. W. (2010). Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. *Research Policy*, 39(4), 495-510. doi:<http://dx.doi.org/10.1016/j.respol.2010.01.022>
- Geels, F. W. (2014). Regime Resistance against Low-Carbon Transitions: Introducing Politics and Power into the Multi-Level Perspective. *Theory, Culture & Society*, 31(5), 21-40. doi:10.1177/0263276414531627
- Geels, F. W. (2020). Micro-foundations of the multi-level perspective on socio-technical transitions: Developing a multi-dimensional model of agency through crossovers between social constructivism, evolutionary economics and neo-institutional theory. *Technological Forecasting and Social Change*, 152. doi:10.1016/j.techfore.2019.119894
- Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research Policy*, 36(3), 399-417. doi:<http://dx.doi.org/10.1016/j.respol.2007.01.003>

- Gibbs, D., & O'Neill, K. (2014). The green economy, sustainability transitions and transition regions: a case study of Boston. *Geografiska Annaler: Series B, Human Geography*, 96(3), 201-216. doi:10.1111/geob.12046
- Göpel, M. (2016). *The Great Mindshift: How a New Economic Paradigm and Sustainability Transformations go Hand in Hand*. Cham: Springer.
- Griliches, Z. (1957). Hybrid Corn: An Exploration in the Economics of Technological Change. *Econometrica*, 25(4), 501-522. doi:10.2307/1905380
- Grin, J., Rotmans, J., & Schot, J. (2010). *Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change*. London, UNITED KINGDOM: Taylor & Francis Group.
- Gunderson, L. H., & Holling, C. S. (2002). *Panarchy: Understanding transformations in human and natural systems*. Washington, Covelo, London: Island Press.
- Haberl, H., Wiedenhofer, D., Virág, D., Kalt, G., Plank, B., Brockway, P., . . . Creutzig, F. (2020). A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part II: synthesizing the insights. *Environmental Research Letters*, 15(6), 065003. doi:10.1088/1748-9326/ab842a
- Halbe, J., Adamowski, J., & Pahl-Wostl, C. (2015). The role of paradigms in engineering practice and education for sustainable development. *Journal of Cleaner Production*, 106, 272-282. doi:<https://doi.org/10.1016/j.jclepro.2015.01.093>
- Hall, C. A. S., & Day, J. W. (2009). Revisiting the Limits to Growth After Peak Oil: In the 1970s a rising world population and the finite resources available to support it were hot topics. Interest faded—but it's time to take another look. *American Scientist*, 97(3), 230-237. Retrieved from <http://www.jstor.org.tudelft.idm.oclc.org/stable/27859331>
- Hamilton, K. (1995). Sustainable development, the Hartwick rule and optimal growth. *Environmental and Resource Economics*, 5(4), 393-411. doi:10.1007/BF00691576
- Hamilton, R. T. V., & Ramcilovic-Suominen, S. (2023). From hegemony-reinforcing to hegemony-transcending transformations: horizons of possibility and strategies of escape. *Sustainability Science*, 18(2), 737-748. doi:10.1007/s11625-022-01257-1
- Herrero, M., Thornton, P. K., Mason-D'Croz, D., Palmer, J., Benton, T. G., Bodirsky, B. L., . . . West, P. C. (2020). Innovation can accelerate the transition towards a sustainable food system. *Nature Food*, 1(5), 266-272. doi:10.1038/s43016-020-0074-1
- Hickel, J., & Kallis, G. (2020). Is Green Growth Possible? *New Political Economy*, 25(4), 469-486. doi:10.1080/13563467.2019.1598964
- Holden, N. M., Neill, A. M., Stout, J. C., O'Brien, D., & Morris, M. A. (2023). Biocircularity: a Framework to Define Sustainable, Circular Bioeconomy. *Circular Economy and Sustainability*, 3(1), 77-91. doi:10.1007/s43615-022-00180-y
- Jickling, B. (2016). Losing traction and the art of slip-sliding away: Or, getting over education for sustainable development. *The Journal of Environmental Education*, 47(2), 128-138. doi:10.1080/00958964.2015.1080653
- Kates, R. W., & Parris, T. M. (2003). Long-term trends and a sustainability transition. *Proceedings of the National Academy of Sciences*, 100(14), 8062-8067. doi:10.1073/pnas.1231331100
- Kaya Kanlı, N., & Küçükefe, B. (2023). Is the environmental Kuznets curve hypothesis valid? A global analysis for carbon dioxide emissions. *Environment, Development and Sustainability*, 25(3), 2339-2367. doi:10.1007/s10668-022-02138-4

- Keller, M., Sahakian, M., & Hirt, L. F. (2022). Connecting the multi-level-perspective and social practice approach for sustainable transitions. *Environmental Innovation and Societal Transitions*, 44, 14-28. doi:10.1016/j.eist.2022.05.004
- 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. doi:<https://doi.org/10.1016/j.eist.2022.06.002>
- Köhler, J., Geels, F. W., Kern, F., Markard, J., Onsongo, E., Wieczorek, A., . . . Wells, P. (2019). An agenda for sustainability transitions research: State of the art and future directions. *Environmental Innovation and Societal Transitions*, 31, 1-32. doi:<https://doi.org/10.1016/j.eist.2019.01.004>
- Kuhn, T. S. (2012). *The Structure of Scientific Revolutions: 50th Anniversary Edition* (4th edition ed.). Chicago: The University of Chicago Press.
- Kurzman, C., & Owens, L. (2002). The Sociology of Intellectuals. *Annual Review of Sociology*, 28(1), 63-90. doi:10.1146/annurev.soc.28.110601.140745
- Le Cacheux, J., & Laurent, E. (2015). The EU “Beyond GDP”. In *Report on the State of the European Union: Is Europe Sustainable?* (pp. 154-167). London: Palgrave Macmillan UK.
- Leach, M., Stirling, A. C., & Scoones, I. (2010). *Dynamic Sustainabilities: Technology, Environment, Social Justice* (1st edition ed.): Routledge.
- Lee, H., & Romero, J. (2023). *Summary for Policymakers. In: Climate Change 2023: Synthesis Report. A Report of the Intergovernmental Panel on Climate Change. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, . Retrieved from Geneva, Switzerland: [https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC\\_AR6\\_SYR\\_SPM.pdf](https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_SPM.pdf)
- Leeuwis, C., Boogaard, B. K., & Atta-Krah, K. (2021). How food systems change (or not): governance implications for system transformation processes. *Food Security*, 13(4), 761-780. doi:10.1007/s12571-021-01178-4
- Lepenies, P. (2016). *The Power of a Single Number: A Political History of GDP*: Columbia University Press.
- Loorbach, D., Frantzeskaki, N., & Avelino, F. (2017). Sustainability Transitions Research: Transforming Science and Practice for Societal Change. *Annual Review of Environment and Resources*, 42(1), 599-626. doi:10.1146/annurev-environ-102014-021340
- Lozano, R., Lozano, F. J., Mulder, K., Huisingh, D., & Waas, T. (2013). Advancing Higher Education for Sustainable Development: international insights and critical reflections. *Journal of Cleaner Production*, 48, 3-9. doi:<https://doi.org/10.1016/j.jclepro.2013.03.034>
- Ludwig, D., & Ruphy, S. (2021). Scientific Pluralism. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy*.
- MacLeod, M., Arp, H. P. H., Tekman, M. B., & Jahnke, A. (2021). The global threat from plastic pollution. *Science*, 373(6550), 61-65. doi:doi:10.1126/science.abg5433
- Marín, A., & Goya, D. (2021). Mining—The dark side of the energy transition. *Environmental Innovation and Societal Transitions*, 41, 86-88. doi:<https://doi.org/10.1016/j.eist.2021.09.011>
- Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy*, 41(6), 955-967. doi:<http://dx.doi.org/10.1016/j.respol.2012.02.013>

- Marletto, G., Franceschini, S., Ortolani, C., & Sillig, C. (2016). *Mapping Sustainability Transitions*. Cham: Springer.
- Mathur, D., Gregory, R., & Imran, M. (2022). Transitioning towards a circular economy solar energy system in Northern Australia: insights from a multi-level perspective. *Australian Planner*, 58(3-4), 115-122. doi:10.1080/07293682.2023.2200956
- Meadows, D. (2010). *Die Grenzen des Denkens: Wie wir sie mit System erkennen koennen und ueberwinden koennen* (K. Bossel & H. Bossel, Trans.). Muenchen: oekom.
- Mokyr, J. (2005). Chapter 17 - Long-Term Economic Growth and the History of Technology. In P. Aghion & S. N. Durlauf (Eds.), *Handbook of Economic Growth* (Vol. 1, pp. 1113-1180): Elsevier.
- Naberhaus, M., Ashford, C., Buhr, M., Hanisch, F., Şengün, K., & Tunçer, B. (2011). *Effective change strategies for the Great Transition: Five leverage points for civil society organisations*. Retrieved from <https://base.socioeco.org/docs/smartcsosreportfinal.pdf>
- Nilsen, H. R. (2010). The joint discourse 'reflexive sustainable development' — From weak towards strong sustainable development. *Ecological Economics*, 69(3), 495-501. doi:<https://doi.org/10.1016/j.ecolecon.2009.11.011>
- Paddock, W. C. (1970). How Green Is the Green Revolution? *BioScience*, 20(16), 897-902. doi:10.2307/1295581
- Pakes, A., & Sokoloff, K. L. (1996). Science, technology, and economic growth. *Proceedings of the National Academy of Sciences*, 93(23), 12655-12657. doi:10.1073/pnas.93.23.12655
- Palm, A. (2022). Innovation systems for technology diffusion: An analytical framework and two case studies. *Technological Forecasting and Social Change*, 182, 121821. doi:<https://doi.org/10.1016/j.techfore.2022.121821>
- Prados, M.-J., Iglesias-Pascual, R., & Barral, Á. (2022). Energy transition and community participation in Portugal, Greece and Israel: Regional differences from a multi-level perspective. *Energy Research & Social Science*, 87, 102467. doi:<https://doi.org/10.1016/j.erss.2021.102467>
- Pregernig, M. (2014). Framings of science-policy interactions and their discursive and institutional effects: examples from conservation and environmental policy. *Biodiversity and Conservation*, 23(14), 3615-3639. doi:10.1007/s10531-014-0806-3
- Pungas, L. (2023). Invisible (bio)economies: a framework to assess the 'blind spots' of dominant bioeconomy models. *Sustainability Science*. doi:10.1007/s11625-023-01292-6
- Raffer, K., & Singer, H. W. (2001). *The Economic North-South Divide: Six decades of unequal development*. Cheltenham, Northampton: Edward Elgar.
- Ramcilovic-Suominen, S., Kröger, M., & Dressler, W. (2022). From pro-growth and planetary limits to degrowth and decoloniality: An emerging bioeconomy policy and research agenda. *Forest Policy and Economics*, 144, 102819. doi:<https://doi.org/10.1016/j.forpol.2022.102819>
- Rockström, J., Gupta, J., Qin, D., Lade, S. J., Abrams, J. F., Andersen, L. S., . . . Zhang, X. (2023). Safe and just Earth system boundaries. *Nature*. doi:10.1038/s41586-023-06083-8
- Rockstrom, J., Steffen, W., Noone, K., Persson, A., Chapin, F. S., Lambin, E. F., . . . Foley, J. A. (2009). A safe operating space for humanity. *Nature*, 461(7263), 472-475. Retrieved from <http://dx.doi.org/10.1038/461472a>
- Rogers, E. R. (1983). *Diffusion of Innovations*. New York: The Free Press.

- Rosenberg, N. (1974). Science, Invention and Economic Growth. *The Economic Journal*, 84(333), 90-108. doi:10.2307/2230485
- Rostow, W. W. (1969). *The Stages of Economic Growth: A Non-Comunist Manifesto*. USA: Cambridge.
- Ruggeri, E., & Garrido, S. (2021). More renewable power, same old problems? Scope and limitations of renewable energy programs in Argentina. *Energy Research & Social Science*, 79, 102161. doi:<https://doi.org/10.1016/j.erss.2021.102161>
- Schlaile, M. P., & Urmetzer, S. (2021). Transitions to Sustainable Development. In W. Leal Filho, A. M. Azul, L. Brandli, A. Lange Salvia, & T. Wall (Eds.), *Decent Work and Economic Growth* (pp. 1067-1081). Cham: Springer International Publishing.
- Schlüter, M., Caniglia, G., Orach, K., Bodin, Ö., Magliocca, N., Meyfroidt, P., & Reyers, B. (2022). Why care about theories? Innovative ways of theorizing in sustainability science. *Current Opinion in Environmental Sustainability*, 54, 101154. doi:<https://doi.org/10.1016/j.cosust.2022.101154>
- Schmelzer, M. (2015). The growth paradigm: History, hegemony, and the contested making of economic growthmanship. *Ecological Economics*, 118, 262-271. doi:<https://doi.org/10.1016/j.ecolecon.2015.07.029>
- Schmelzer, M. (2017). *The Hegemony of Growth: The OECD and the Making of the Economic Growth Paradigm*. Cambridge: Cambridge University Press.
- Schöneberg, J., & Häckl, M. K. (2020). It is time to abandon “development” goals and demand a post-2030 Utopia. Retrieved from <http://www.developmentresearch.eu/?p=762>
- Schumacher, E. F. (1973). *Small is beautiful: die Rückkehr zum menschlichen Maß* (K. A. Klewer, Trans. German Edition ed.). München: OEKOM.
- Scoones, I., Stirling, A., Abrol, D., Atela, J., Charli-Joseph, L., Eakin, H., . . . Yang, L. (2020). Transformations to sustainability: combining structural, systemic and enabling approaches. *Current Opinion in Environmental Sustainability*, 42, 65-75. doi:<https://doi.org/10.1016/j.cosust.2019.12.004>
- Sharpe, B., Hodgson, A., Leicester, G., Lyon, A., & Fazey, I. (2016). Three horizons: a pathways practice for transformation. *Ecology and Society*, 21(2). doi:10.5751/ES-08388-210247
- Solivetti, L. M. (2005). W.W. Rostow and His Contribution to Development Studies: A Note. *The Journal of Development Studies*, 41(4), 719-724. doi:10.1080/00220380500092903
- Solow, R. M. (1974). The Economics of Resources or the Resources of Economics. *The American Economic Review*, 64(2), 1-14. Retrieved from [www.jstor.org/stable/1816009](http://www.jstor.org/stable/1816009)
- Sovacool, B. K., & Hess, D. J. (2017). Ordering theories: Typologies and conceptual frameworks for sociotechnical change. *Social Studies of Science*, 47(5), 703-750. doi:10.1177/0306312717709363
- Tabrizian, S. (2019). Technological innovation to achieve sustainable development—Renewable energy technologies diffusion in developing countries. *Sustainable Development*, 27(3), 537-544. doi:<https://doi.org/10.1002/sd.1918>
- Unerman, J. (2020). Risks from self-referential peer review echo chambers developing in research fields: 2018 Keynote Address presented at The British Accounting Review 50th Anniversary Celebrations, British Accounting and Finance Association Annual Conference, London. *The British Accounting Review*, 52(5), 100910. doi:<https://doi.org/10.1016/j.bar.2020.100910>

- United Nations. (2015). *Transforming our world: the 2030 Agenda for Sustainable Development*. (A/RES/70/1). The General Assembly Retrieved from <https://documents-dds-ny.un.org/doc/UNDOC/GEN/N15/291/89/PDF/N1529189.pdf?OpenElement>
- United Nations. (2023). *Progress towards the Sustainable Development Goals: Towards a Rescue Plan for People and Planet. Report of the Secretary-General (Special Edition)*. Retrieved from <https://hlpf.un.org/sites/default/files/2023-04/SDG%20Progress%20Report%20Special%20Edition.pdf>
- Vandeventer, J. S., Cattaneo, C., & Zografos, C. (2019). A Degrowth Transition: Pathways for the Degrowth Niche to Replace the Capitalist-Growth Regime. *Ecological Economics*, 156, 272-286. doi:<https://doi.org/10.1016/j.ecolecon.2018.10.002>
- Walker, B., Holling, C. S., Carpenter, S. R., & Kinzig, A. (2004). Resilience, adaptability and transformability in social–ecological systems. *Ecology and Society*, 9(2). Retrieved from <http://www.ecologyandsociety.org/vol9/iss2/art5/>
- Wanner, T. (2015). The New ‘Passive Revolution’ of the Green Economy and Growth Discourse: Maintaining the ‘Sustainable Development’ of Neoliberal Capitalism. *New Political Economy*, 20(1), 21-41. doi:10.1080/13563467.2013.866081
- Watari, T., McLellan, B. C., Giurco, D., Dominish, E., Yamasue, E., & Nansai, K. (2019). Total material requirement for the global energy transition to 2050: A focus on transport and electricity. *Resources, Conservation and Recycling*, 148, 91-103. doi:<https://doi.org/10.1016/j.resconrec.2019.05.015>
- Wharton, C. R., Jr. (1969). The Green Revolution: Cornucopia or Pandora's Box? *Foreign Affairs (pre-1986)*, 47(000003), 464. Retrieved from <https://doi.org/10.2307/20039390>
- Williams, J. B., & McNeill, J. M. (2005). *The Current Crisis In Neoclassical Economics and the Case for an Economic Analysis Based on Sustainable Development*. Retrieved from
- Wittmayer, J. M., & Schöpke, N. (2014). Action, research and participation: roles of researchers in sustainability transitions. *Sustainability Science*, 9(4), 483-496. doi:10.1007/s11625-014-0258-4
- Woiwode, C., Schöpke, N., Bina, O., Veciana, S., Kunze, I., Parodi, O., . . . Wamsler, C. (2021). Inner transformation to sustainability as a deep leverage point: fostering new avenues for change through dialogue and reflection. *Sustainability Science*. doi:10.1007/s11625-020-00882-y