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Decline: an emerging frontier for the study and practice of decarbonization

Daniel Rosenbloom[1] & Adrian Rinscheid[2]
[1] University of Toronto, Department of Political Science
[2] University of St. Gallen, Institute for Economy and the Environment

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Abstract
It is increasingly well understood that decarbonization will require sustained efforts to encourage the rapid emergence and widespread diffusion of an array of complementary low-carbon innovations, giving rise to new carbon-neutral societal systems spanning from transport to agri-foods. The role of innovation has, therefore, been a central preoccupation within both the practice and theory surrounding climate change mitigation. However, deep lock-ins suggest that existing carbon-intensive systems will not be displaced or reconfigured by innovation alone. Rather, it is more appropriate to consider both innovation and decline as inextricably interlinked in the pursuit of decarbonization. There is a growing recognition of this in both research and practice, with a recent proliferation of studies and efforts engaging with the deliberate decline of carbon-intensive systems and their components (e.g., technologies). Yet, despite this, the role of intentional decline in decarbonization remains poorly understood and the emerging body of research in this area continues to be dispersed among different strands of literature and disciplines. In response, this article structures the fragmented strands of research engaging with conscious decline, interrogating the role it may play in decarbonization. It does so by systematically surveying concepts with particular relevance for intentional decline, focusing on phase-out, divestment, and destabilization.

1. Introduction

In order to meet the climate targets set by the Paris agreement, societal systems such as electricity, transport, and agri-foods will need to be actively decarbonized over the coming decades (IPCC, 2018). It is increasingly well understood that this will involve sustained efforts to encourage the rapid emergence and widespread diffusion of an array of complementary low-carbon innovations, spanning from technologies (e.g., renewable energy sources and electric vehicles) to practices (e.g., conservation and plant-based diets) to business models (e.g., mobility-as-a-service and farm-to-table). Through the development and deployment of low-carbon innovations, new carbon-neutral systems are expected to take shape. Scholars and practitioners have, therefore, focused heavily on the role of innovation in driving decarbonization. Prominent debates have, for instance, revolved around the governance of innovation (Edler and Boon, 2018; Hekkert et al., 2007; Mazzucato, 2013), how low-carbon innovations might scale up and be made durable (Bernstein and Hoffmann, 2018; Levin et al., 2012), the social acceptance of low-carbon innovations (Wüstenhagen et al., 2007), processes of experimentation and learning-by-doing (Brown et al., 2003; Manne and Richels, 2004), the relative emphasis of innovation policy on market creation or research and development (Peters et al., 2012), along with how such innovation processes can be accounted for in modelling efforts (Löschel, 2002).

Yet, while innovation is undeniably central to decarbonization, concentrating too heavily on innovation may inadvertently underappreciate the degree to which existing carbon-intensive systems are locked in (Arthur, 1989; Unruh, 2000). Carbon lock-in manifests through a range of factors, including the sunk costs associated with the current system, the accumulation of experience around established technologies and institutions, self-fulfilling expectations about the persistence of these arrangements, entrenched interests tied to longstanding development trajectories, and so on. Seto et al., (2016) have usefully grouped these lock-ins into three general categories, which work together to reproduce carbon-intensive trajectories: (1) technological and infrastructural patterns, (2) institutions and decision-making at various levels, and (3) individual behaviors along with social structural forces such as routines and discourses.

The depth of carbon lock-in is exemplified by the challenges facing new renewable energy sources in the electric power system. While these novelties have benefited from decades of innovation policy (both technology push and market pull) and have shown promising signs of broad uptake, they have to date failed to capture a large share of the market. Renewable energy sources (excluding large hydropower) accounted for 12.9 percent of electricity worldwide in 2018 (UNEP & BNEF, 2019), whereas almost two thirds of global electricity generation were still based on coal and natural gas (IEA, 2019). Moreover, fossil fuel electricity sources continue to expand globally, benefiting from global investments amounting to US $95 billion in 2018 (UNEP & BNEF, 2019). These investments stand in sharp contrast to climate aspirations and the projected place of new renewables in a low-carbon future (IPCC, 2018). In this context, Geels (2014, pp. 36–37) has cautioned that "policymakers (and many academics) have high (probably unrealistic) hopes that 'green' innovation will be sufficient".

In response, various strands of research have begun to explore how actively steering the *decline* of carbon-intensive systems could make way for the emergence of alternatives. Turnheim and Geels (2012) have, for instance, examined the role of destabilizing existing systems, referring to this as the "flipside" of innovation processes. Kivimaa and Kern (2016), similarly, investigate policy mixes to simultaneously drive the motors of innovation and destruction. An increasing

number of studies have focued on the phase-out of carbon-intensive technologies, infrastructures, and processes (Meckling and Nahm, 2019; Rentier et al., 2019). Divestment has also attracted growing interest as a way to understand the place of finance and political activism in promoting the decline of fossil fuels (Braungardt et al., 2019; Hestres and Hopke, 2019).

Cases of intentional decline are also increasingly commonplace in climate policy and practice. Consider, for instance, the ongoing and emerging efforts focused on phasing out coal-fired power generation (Jewell et al., 2019; Rosenbloom, 2018), inefficient lightbulbs (Howarth and Rosenow, 2014), and internal combustion automobiles (Meckling and Nahm, 2019). There are also a number of policy measures and broader societal efforts that seek the removal of subsidies and other financial resources from fossil fuel interests (Le Billon and Kristoffersen, 2019). Taken together, deliberate decline is already playing a role in efforts to overcome carbon lock-in and is perhaps more accurately viewed as inextricably interlinked with low-carbon innovation.

Despite this, neither the character of deliberate decline nor its implications for future research and practice have been deeply or systematically scrutinized. As a corrective, this article seeks to interrogate the meaning and role of conscious decline in the context of decarbonization. It poses the following questions: (1) how is deliberate decline variously understood in the context of decarbonization; (2) what are its prominent features; and (3) what might this suggest for future research and practice? In order to address these questions, we systematically survey and trace the development of concepts that directly engage with the deliberate decline of carbon-intensive systems and their components, focusing on phase-out, divestment, and destabilization.

Our findings suggest that phase-out, divestment, and destabilization offer different yet complementary ways of approaching intentional decline in the context of decarbonization. These three concepts foreground differing sources of carbon lock-in and offer compatible models of how to overcome them. While phase-out emphasizes the managed termination of carbon-intensive technologies and infrastructures, divestment centers on the erosion of both the financial resources and political legitimacy of the fossil fuel industry. Destabilization offers a broader perspective by focusing on the transformation of entire carbon-intensive systems including not only material components but also supporting configurations of interests, institutions, markets, and practices. As part of this, each concept also places emphasis on different drivers of decline, spanning from the regulatory authority of the state to more complex and multi-actor processes. Bringing these concepts together, we shed light on the multifaceted character of conscious decline, bridge the fragmented contributions in this space, and uncover implications for future research and practice.

2. Scope and Methods

The core aim of this study is to shed light on the diverse ways in which deliberate decline is being approached in the context of decarbonization in order to generate lessons for research and practice. To address this aim, we explore prominent concepts engaging with intentional decline drawn from the scholarly literature. The selection of concepts was guided by the following considerations: (1) the concept engages directly with the conscious decline of carbon-intensive systems (e.g., fossil fuel-based mobility or electricity) or their components (e.g., gasoline-powered cars or coal-fired power); (2) a problem-orientation – the concept is used not only to understand the decarbonization challenge but also to address it through policy and practice; and (3) the concept is comparatively prominent within the literature on decarbonization.

Taking these considerations into account and based on several exploratory investigations of other candidate concepts, phase-out, divestment, and destabilization were selected for in-depth analysis. *Phase-out* is widely studied and is currently playing a central role in managing the decline of coal, internal combustion engine vehicles, and other carbon-intensive arrangements. *Divestment* has begun to garner considerable interest within scholarly work and forms the cornerstone of efforts by civil society and other actors to undermine the position of the fossil fuel industry along with its associated financial base, business models, and interests. While it is only now gaining traction among policy communities, *destabilization* has encouraged the emergence of a rapidly growing body of work within the field of sustainability transitions which explicitly engages with the process that upsets the stability of established carbon-intensive systems along with the functions policy can fulfill to facilitate the breakup of such systems. The selection of these concepts was further cross-checked through consultations with experts at several scholarly gatherings.

Informed by perspectives on qualitative systematic reviews (Dixon-Woods et al., 2006) and conceptual innovation (Meadowcroft and Fiorino, 2017), a systematic survey of the English-language scholarly literature was deployed to analyze each of these concepts. The data collection and sampling strategy consisted of three phases. The first entailed keyword searches of the SCOPUS database of academic literature (see the Appendix for specific search strings and steps used for each concept) followed by a close review of all article abstracts to eliminate false positives (e.g., out of scope). Note that the specific context surrounding each term necessitated a careful calibration of search terms (e.g., destabilization returns hundreds of false positives if only limited to decarbonization given its use in relation to the stability of ecosystems). During the second phase, the full texts were scanned to assess whether they substantively engaged with a given concept, eliminating those that did not permit for deeper analysis (in line with the three themes listed below). Finally, we supplemented the SCOPUS search with reference tracing (examining the works cited in relevant articles), consultations with experts, and the knowledge of the authors.

This body of literature was then subject to in-depth review, with three themes in mind: (1) what are the roots of the concept in theory and practice; (2) how is the concept understood; (3) how does the concept represent decline (the unit undergoing decline, the model of decline, and the primary drivers of decline). The results of this analysis are presented in the next section.

3. Engaging with decline

This study examines three prominent concepts that directly engage with the conscious decline of carbon-intensive systems and their components: phase-out, divestment, and destabilization. Each of these concepts highlights different dimensions of deliberate decline (from system components to entire systems), emerges from distinct settings (from policy to civil society to academia), and has been used for different purposes (to orient a regulatory response, mobilize societal actors, or better understand how decline occurs and potential areas for intervention).

While we focus on these three concepts, there are many others that may shed light on further (and sometimes less conscious) aspects of decline. *Discontinuation*, for instance, has attracted somewhat less sustained interest among policy scholars working on decarbonization to capture the purposeful abandonment, dismantling, or termination of governance structures that support

current trajectories (Hoffmann et al., 2017; Stegmaier et al., 2014). Similarly, there is a more limited body of literature invoking *exnovation* to refer to the intentional erosion of carbon-intensive technological trajectories through policy intervention (David, 2017; David and Gross, 2019). Research on *disruption* from the business management literature (Christensen, 1997) has also garnered attention within scholarly discourse around decarbonization (Wilson and Tyfield, 2018). Originating from outside of the decarbonization literature, this concept has typically focused on processes of innovation – i.e., disruptive innovation – relating to the emergence of novel business strategies with the potential to upset current markets and the position of incumbent firms. However, some have suggested that disruption may also apply to changes in actor networks, ownership patterns, and regulations that place pressure on established systems (Johnstone et al., 2020). More encompassing even, *degrowth* has been used to contemplate the decline of entire political-economic paradigms – i.e., capitalism and compatible notions of green economic growth – in order to realize socio-ecological transformation (Demaria et al., 2013). While both discontinuation and exnovation are concerned with the deliberate decline of carbon-intensive systems, their uptake within the literature on decarbonization has been somewhat limited to date (see Figure 1). Disruption and degrowth concentrate on less conscious processes and broader phenomena, respectively. We, therefore, focus on phase-out, divestment, and destabilization in the review that follows.

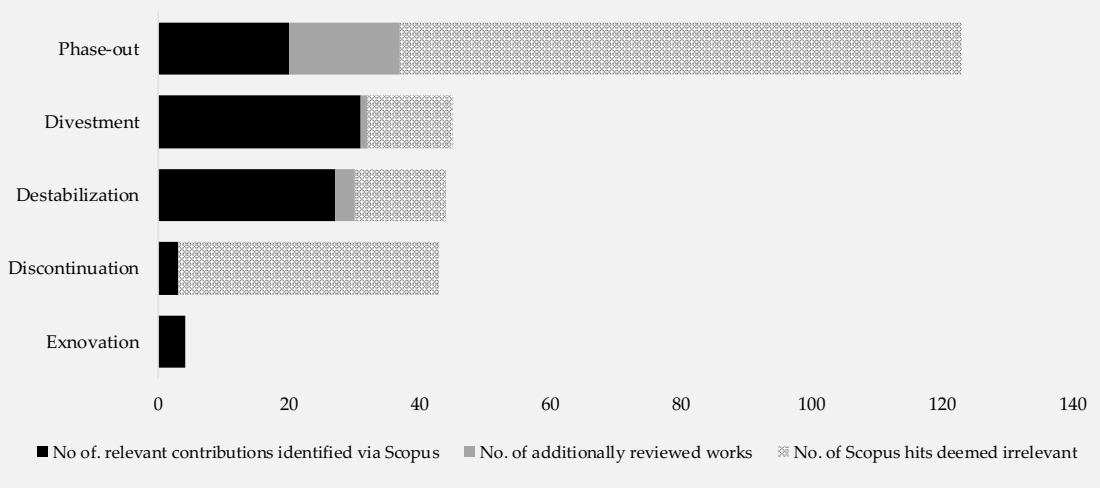


Figure 1: relative prominence of concepts engaging with deliberate decline
This figure is based on the search strings used to query the SCOPUS database (see Appendix) and the approach described in Section 2.

3.1 Phase-out

In its linguistic meaning, the verb "to phase (something) out" means "to discontinue the practice, production, or use of [something] by phases".[1] The noun "phaseout" (or "phase-out") was used for the first time in 1951, referring to "a gradual stopping (as in operations or production)" or "a closing down by phases".[1] Regarding the scholarly literature, early mentions of phase-out date back to the 1970s. In an article examining public anxiety concerning air pollution from power stations in the US, Friedlander (1970) used the term to describe the (expected) shift from fossil fuel to nuclear power.

[1] See https://www.merriam-webster.com/dictionary/phaseout

In terms of practical application to environmental problems, the regulation of lead in gasoline provides an early example (Falk, 1977). After the health impacts of lead exposure from automobile emissions became widely known, countries started adopting regulations to limit the maximum allowed lead content (Lovei, 1998). These regulations were ratcheted up over time, leading to a complete and global termination of lead in gasoline in 2013. Other examples include plans to gradually lower the reliance on nuclear power in Sweden (Kaijser, 1992) and Germany (Mez and Piening, 2002), the global phase-out of ozone-depleting substances (Morrisette, 1989), and the termination of ocean waste incineration in the North Sea (Ditz, 1989). What unites these cases is that the element undergoing decline is a specific technology (e.g., nuclear power), substance (e.g., lead), or process (e.g., ocean incineration) associated with a negative externality deemed intolerable. The ultimate goal of a phase-out is to terminate the use of such elements.

In the context of decarbonization, the academic literature on phase-out can broadly be organized according to two perspectives. The first takes a rather inclusive view by studying the phase-out of fossil fuels (i.e., a substance). Many works adopting this perspective apply economic (e.g., Schwanitz et al., 2014), atmospheric (e.g., Lelieveld et al., 2019) or integrated models with physical and socio-economic components (e.g., Rotmans and Swart, 1990) to examine possible fossil fuel phase-out pathways and implications on socio-economic and bio-physical systems. The second perspective concentrates on the industry or sector level. Here the emphasis is on particular technologies, infrastructures, or processes that contribute to CO_2 emissions. Over the past decade, scholars representing various disciplines have started to study phase-out based on this more industry-oriented perspective, including economics (Edenhofer et al., 2018), geography (Howarth and Rosenow, 2014), political science (Meckling and Nahm, 2019; Rentier et al., 2019), and transition studies (Rosenbloom, 2018; Vögele et al., 2018). As is illustrated in the citation network of 37 academic contributions on phase-out identified during the three phases of data collection (Figure 2), the number of contributions focusing on either of these perspectives is quite balanced, with 17 works taking an inclusive perspective (depicted by triangles) and 20 works adopting an industry-oriented perspective.

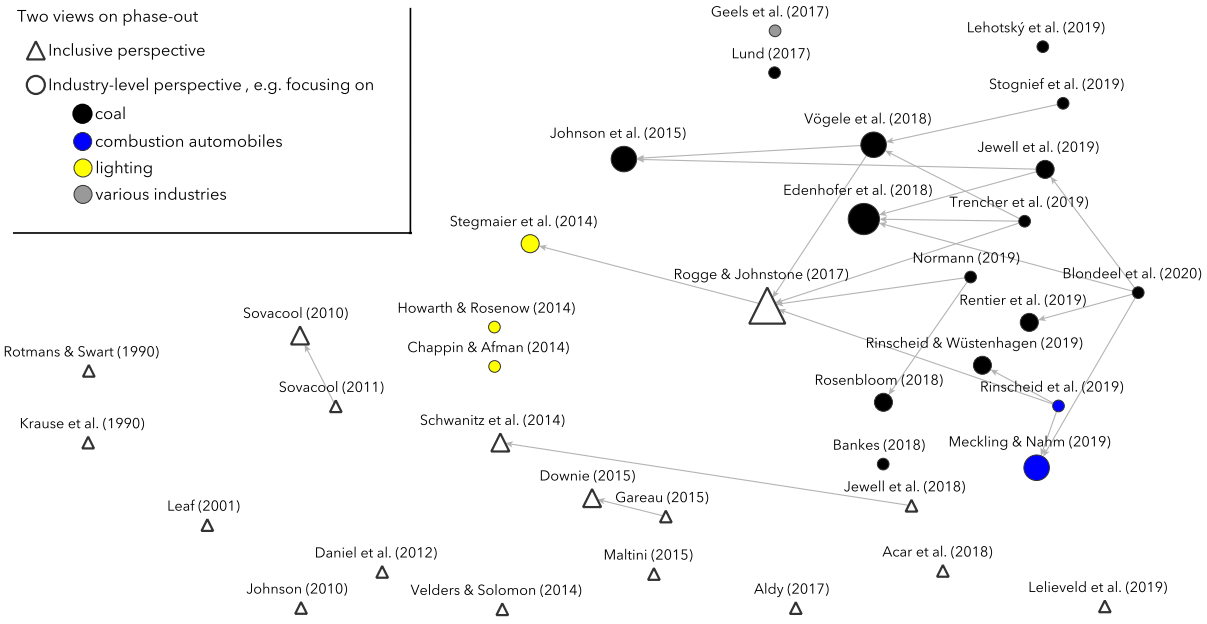


Figure 2: Citation network of scholarly work on phase-out

This figure maps the 37 texts captured by the survey and their referencing patterns. Nodes symbolize individual texts. Arrows depict referencing patterns, with incoming arrows pointing at the text being cited (e.g., Normann, 2019 cites Rogge & Johnstone, 2017). Node size is proportional to the number of incoming citations within the sample. Node color is explained in the figure legend. 16 papers were not cited by other contributions on phase-out.

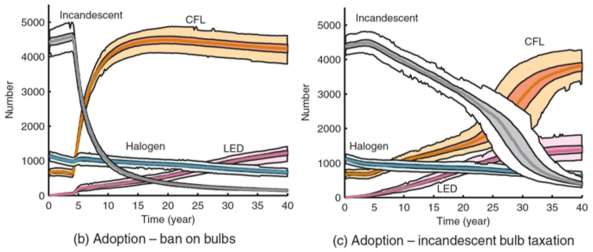
The early uses of the term phase-out in the decarbonization context rely on the broader, inclusive perspective focusing on fossil fuels. Based on an integrated climate assessment model, Rotmans and Swart (1990) concluded that, contingent on the emissions trajectory between 1990 and 2020 and to avoid major risks, fossil fuels may need to be phased out within the 21st century. Krause et al. (1990) developed regionalized 'schedules' and intermediate 'milestones' for the global fossil fuel phase-out, taking political-economic constraints as well as global equity and technological feasibility concerns into account. Their advice to rapidly launch a global fossil fuel phase-out (to be accomplished within the 21st century) was reiterated by several reports published by Greenpeace International (Hare, 1997; Lazarus et al., 1993). In general, however, the notion of a fossil fuel phase-out played a limited role in policy discussions and academic publications on (global) climate policy throughout the 1990s and 2000s and our review led to the identification of almost no scholarly work on phase-out during this period (as depicted in Figure 2). Sovacool (2010) explained this by pointing to the enduring popularity of emissions trading and the associated capture of climate policy debates by the language of markets and economics, concluding that the "discourse on global warming has been prematurely foreclosed" at the expense of other policy options including those targeting the phase-out of fossil fuels (Sovacool, 2010, p. 38).

In the aftermath of the 2009 Pittsburgh G20 summit, at which leaders agreed to "rationalize and phase out over the medium term inefficient fossil fuel subsidies that encourage wasteful consumption"[2], the inclusive perspective was reinvigorated to study fossil fuel subsidy reform (Aldy, 2017; Burniaux and Chateau, 2014; Jewell et al., 2018). In this context, fossil fuel substances are not targeted directly but indirectly through changes in the institutions that are essential in sustaining their market shares. One important finding of this literature is that a phase-out of subsidies alone is not sufficient to terminate fossil fuels and may even lead to higher emissions – therefore, it is recommended to complement fossil fuel subsidy reform with other climate policies (Schwanitz et al., 2014).

Only recently has a growing body of research adopted an industry-level view of phase-out. Some have focused on inefficient light bulbs, investigating the causes and consequences of the European Commission's 2009 regulation on household lighting (Chappin and Afman, 2013; Howarth and Rosenow, 2014). A considerable number of works have emerged since 2015 on coal phase-outs as indicated by the rightmost part of Figure 2 (Blondeel et al., 2020; Johnson et al., 2015; Lehotský et al., 2019; Rinscheid and Wüstenhagen, 2019; Rosenbloom, 2018). Over the past year or so, researchers have also begun to investigate the phase-out of internal combustion engine cars (Meckling and Nahm, 2019; Rinscheid et al., 2020). Taken together, this literature suggests that various policy instruments may help promote the phase-out of particular technologies or infrastructures (see Figure 3). While a technology ban represents the most straightforward policy instrument, other approaches include changes in market rules (e.g., carbon

[2] See http://www.g20.utoronto.ca/2009/2009communique0925.html

taxes), reduced support for high-carbon technologies (e.g., removal of subsidies for coal mining), performance standards that rise in stringency over time, as well as policies that affect institutional rules, policy networks, or social norms associated with carbon-intensive systems (Edenhofer et al., 2018; Geels et al., 2017). Meckling and Nahm (2019) highlight the role of economic competition as a potential driver of technology phase-outs, arguing that the international diffusion of political signals to ban internal combustion engines is rooted in a green industrial policy competition for alternative transport technologies.



Phase		The future distribution of the following lamps will be prohibited
1	September 1st, 2009	Frosted lamps (exception: EEL Class A bulbs) Clear lamps > =80 W
2	September 1st, 2010	Clear lamps > 65 W
3	September 1st, 2011	Clear lamps > 45 W
4	September 1st, 2012	Clear lamps > 7 W
5	September 1st, 2013	Increase of quality standards
6	September 1st, 2014	Lamps with EEL Class C

Figure 3: Depictions of phase-out

The images to the left illustrates that a phase-out may be achieved by different policy instruments (drawn from Chappin and Afman, 2013, p. 30). Based on an agent-based model, they show aggregated purchase decisions by consumers in response to a phase-out of incandescent light bulbs implemented via a ban or taxation. The table to the right illustrates the managed, gradual process of phase-out, taking the phase-out schedule of incandescent light bulbs in the European Union as an example (drawn from Howarth and Rosenow, 2014 p. 742).

Empirical research adopting an industry-level perspective has attended to a variety of political factors surrounding phase-outs, including the political processes leading to the (non-)adoption of phase-out policies (Rentier et al., 2019; Rosenbloom, 2018) and public attitudes towards such policies (Rinscheid et al., 2020; Rinscheid and Wüstenhagen, 2019). Importantly, technology phase-outs are prone to political resistance by affected industries and regions (Krause et al., 1990; Rentier et al., 2019; Trencher et al., 2019), which requires not only dedicated communication efforts to augment public support, but also policy designs that ease the burden of adjustment, de-risk investments into low-carbon alternatives, and manage infrastructural challenges (Edenhofer et al., 2018; Stognief et al., 2019).

A common theme across both perspectives is that a phase-out typically originates from purposeful authoritative action by governments or other political authorities (e.g., international treaties). These actions span from classic command-and-control forms of regulation (Normann, 2019; Sovacool, 2011; Vögele et al., 2018) to market creation policies such as carbon taxes (Chappin and Afman, 2013). Another shared element is the orderly and often gradual or stepwise process of decline. The idea of a phase-out is that it takes place over a specified period of time, with underlying policies defining the allotted time horizon and its key milestones. As an example from the industry-level perspective, Figure 3 illustrates the gradual phase-out schedule of incandescent light bulbs in the European Union. According to Howarth and Rosenow (2014, p. 744), transition periods can help "reduce the costs of switching to the new system of technology and behaviour by allowing supply chains to develop and by providing a clear signal to the market of the direction of technological change".

Beyond these shared elements, the coherence of the academic literature on phase-out remains limited. This is reflected by the somewhat loosely connected citation network depicted in Figure 2. Connections mostly relate to a coalescence around empirical cases (e.g., coal phase-outs in various countries) and to a lesser extent common lines of conceptual development.

3.2 Divestment

In general terms, divestment refers to "[t]he action or process of selling off subsidiary business interests or investments".[3] Much of the early use of this term originates from the legal domain and remains quite close to the above definition (e.g., Hamilton and Till, 1940). Yet, some also invoke divestment in other contexts to mean the act of giving something up, whether tangible or intangible – e.g., jurisdictional authority (Swanson and King, 1992). A foundational episode within the broader career of this concept surrounds its use in targeting the tobacco industry (Wander and Malone, 2004) and apartheid-era South Africa (Salop, 1989).

In the context of decarbonization, the concept of divestment has gained increasing prominence in relation to the political mobilization, discourse, and strategies targeting fossil fuels – i.e., fossil fuel divestment. In particular, its conceptual development has become intertwined with a *social movement* calling for societal actors to divest from fossil fuel companies (Healy and Debski, 2017). This movement has its roots in campus communities and climate activist networks, who drew inspiration from historical divestment campaigns in an attempt to erode the financial resources and license to operate of fossil fuel companies. Initial targets for fossil fuel divestment focused on particularly problematic extractive processes such as mountaintop-removal coal mining and oilsands development. However, divestment targets expanded to include fossil fuel business models in general (sometimes represented by the top 100 or so fossil fuel companies). The expanding scope of divestment links to the popularization of the notion of unburnable carbon by the co-founder of 350.org, Bill McKibben (2012), in his Rolling Stones article titled "Global Warming's Terrifying New Math". This helped crystallize the core logic of divestment, which sees fossil fuel companies as primarily responsible for climate disruption and calls for the wholesale decline of the fossil fuel industry. Although fossil fuel divestment campaigns have proliferated across university campuses, they have had mixed success in encouraging educational institutions to reconsider their investment portfolios (Grady-Benson and Sarathy, 2016), with some announcing complete (e.g., University of California and University of Edinburgh) or partial (e.g., Stanford University and the University of Oxford) divestment of fossil fuel holdings and others (e.g., Harvard University and the University of Toronto) rejecting calls for divestment altogether, citing risks and other concerns (Braungardt et al., 2019).

Divestment also represents an *investment and policy strategy* that appeals to a much broader audience of societal actors. It can be understood as a "risk management strategy for major economic actors, potentially protecting investors and employees from the negative impact of 'stranded assets' and employment risks" (Healy and Debski, 2017, p. 457). Numerous philanthropic foundations, pension funds, and faith-based organizations have adopted this strategy. According to gofossilfuelfree.org, over 1150 institutions and many more individuals have committed to divest from fossil fuels as of 2019. As part of this, there is also an understanding that the financial resources freed up through divestment can be redirected to accelerate the uptake of low-carbon alternatives – often referred to as a divest-invest strategy.

[3] See https://www.lexico.com/definition/divestment

Some financial institutions (e.g., Wealthsimple) are capitalizing on this trend by offering socially responsible investment portfolios that favor firms developing low-carbon innovations. Divestment also embodies a policy response: "pushing governments to disinvest from fossil fuel projects, asking governments to stop building new fossil fuel infrastructure or giving subsidies to the industry" (Hestres and Hopke, 2019, p. 13). Ireland, for instance, has committed to fully divest from fossil fuels as part of its €8 billion national investment fund. Norway has announced a partial divestment (from coal) for its $1 trillion sovereign wealth fund. A number of municipal governments (e.g., New York City and San Francisco) have also moved to divest from fossil fuels.

Beyond this, divestment represents a novel *political discourse*. Rising interest in divestment can be seen as a response to contemporary climate policy and politics, which have failed to appreciate the depth of the climate challenge or move rapidly enough to avert dangerous disruption of the climate system (Linnenluecke et al., 2015). Divestment narratives paint the fossil fuel industry as the core causal force behind climate change and an enemy to long-term prosperity (Ayling and Gunningham, 2017; Mangat et al., 2018). In this fashion, it offers a novel problem frame that seeks to avoid policy and political inaction incumbered by complex causes (e.g., the differentiated responsibilities among nations, industries, and individuals) and solutions (from carbon pricing to performance standards). Rather, it foregrounds the role of upstream fossil fuel production as opposed to diverse downstream consumptive practices. In doing so, divestment offers a clear remedy – society needs to do away with its reliance on this energy source and its associated industrial base (Healy and Debski, 2017).

This discussion reveals that divestment has multiple targets that underlie its model of decline (see Figure 4). Viewing fossil fuel divestment as an investment and policy strategy places weight on the aggregation of investment decisions across a range of societal actors as a direct means to erode the financial position of fossil fuel companies (Hunt et al., 2017; Hunt and Weber, 2019). In contrast, understanding divestment as a novel political discourse foregrounds the importance of legitimacy struggles in undermining the license to operate of the fossil fuel industry (Ayling, 2017; Bergman, 2018). Conceiving divestment as a social movement emphasizes its role in empowering climate activist networks and resisting fossil fuel interests, with the aim of correcting the impacts and inequalities stemming from environmentally damaging business models and practices (Bratman et al., 2016; Healy and Barry, 2017). Therefore, the principal unit undergoing decline spans from the financial resources of the fossil fuel industry to its political legitimacy and hold over decision-making.

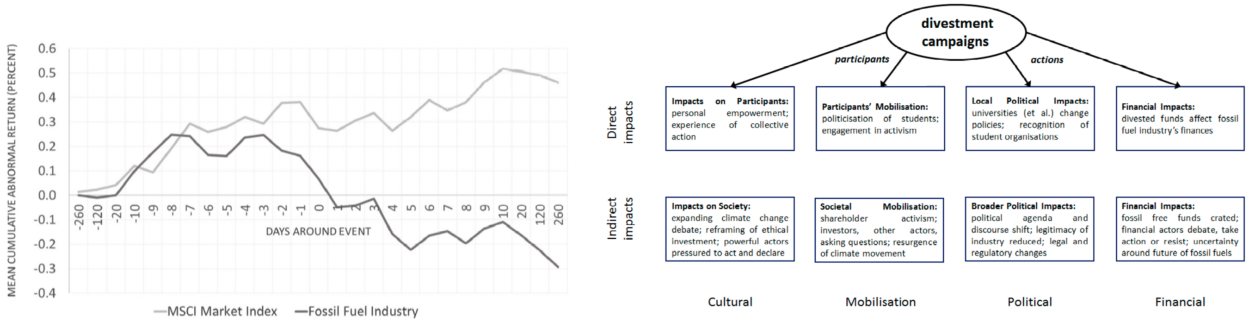


Figure 4: Depictions of divestment

The diverse imagery associated with divestment reflects its multifaceted character. The impact of divestment on the market valuation of fossil fuel industry is depicted on the left (drawn from Dordi and Weber, 2019) and its broader impacts are pictured on the right (drawn from Bergman, 2018).

While these elements should not be viewed as mutually exclusive, certain texts emphasize particular aspects based on disciplinary approaches and analytical inclinations (see Figure 5). On the one hand, legal and business scholars may engage with the potential of divestment as an investment strategy, exploring its impact on the share price of fossil fuel firms (Dordi and Weber, 2019) or its compatibility with the principles of fiduciary responsibility (Sarang, 2015). Political scientists and policy scholars may, on the other hand, call attention to discursive (Mangat et al., 2018) or social movement dynamics (Stephens et al., 2018). Nevertheless, there is considerable interconnection among these perspectives as evidenced by the densely interwoven citation network.

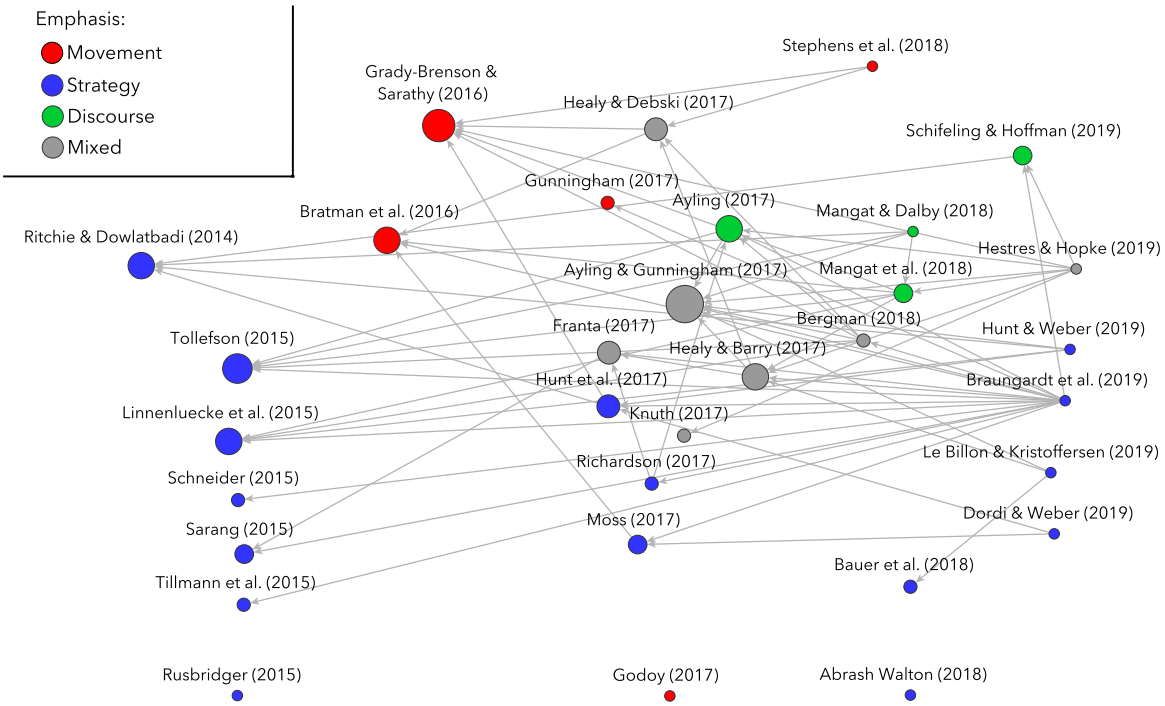


Figure 5: Citation network of scholarly work on divestment
This figure maps the 32 texts captured by the survey and their referencing patterns. Nodes symbolize individual texts. Arrows depict referencing patterns, with incoming arrows pointing at the text being cited (e.g., Hestres & Hopke, 2019 cite Mangat et al., 2018). Node size is proportional to the number of incoming citations within the sample. Node color is explained in the figure legend.

3.3 Destabilization

The term destabilization has been used in various ways in the English language but most commonly refers to "[t]he process of upsetting the stability of a region or system, especially of

government".[4] Within the social sciences, some of the early uses of this term revolve around labor imbalances (Kulp, 1932), economic disequilibrium (Tilman, 1974), and political instability (Henderson, 1973). In the context of environmental challenges, destabilization is sometimes understood as the disruption of delicate balances in natural systems (Rosenzweig, 1971). A common theme in these early uses of destabilization is the perturbation of a system (economic, political, natural, or otherwise).

Engaging with decarbonization, destabilization has recently come to play a prominent role within the field of sustainability transitions, which has its roots in innovation studies and evolutionary economics (Markard et al., 2012). Broadly, destabilization is understood as a central part of low-carbon transition processes and principally relates to the pressures upsetting a dynamically stable socio-technical system such as electricity or mobility. Transitions refer to large-scale shifts in these systems as they move from carbon-intensive to decarbonized configurations. They involve profound and interdependent adjustments to social and technological innovations, infrastructures, institutions, markets, culture, and lifestyles (hence, socio-technical).

Transition perspectives tend to understand these processes and the role of destabilization within them as involving interactions and alignments among three dimensions: niches, regimes, and landscape developments (Geels et al., 2017). Niches are composed of emerging innovations and arrangements that challenge established patterns. Regimes embrace the dominant socio-technical configuration (institutions, actor networks, infrastructures, and technologies) and are characterized by path-dependent features (e.g., sunk costs in infrastructure) that reproduce existing innovation trajectories and carbon-intensive patterns (Berkhout, 2002). The landscape encompasses broader developments (e.g., changing political administrations or shifts in culture) that may help to reinforce or place pressure on established configurations. Transitions are considered to arise from the interactions and alignments among niche dynamics, internal regime-level processes, and landscape developments. The general theory of change is that: "(a) niche-innovations build up internal momentum, through learning processes, price/performance improvements, and support from powerful groups, (b) changes at the landscape level create pressure on the regime and (c) destabilisation of the regime creates windows of opportunity for niche innovations" (Geels and Schot, 2007, p. 400).

From this, destabilization can be understood as "change that affects the regime's core structures, potentially breaking a lock-in" (Martínez Arranz, 2017, p. 127). It embraces the external and internal pressures that upset the dynamic equilibrium of a socio-technical regime and create opportunities for alternatives to emerge and potentially displace the existing configuration (Karltorp and Sandén, 2012). In this way, "[t]he causal relationship between technological novelty and destabilisation is bi-directional: technical alternatives contribute to regime destabilisation, while regime problems create 'windows of opportunity' for the diffusion of new technologies" (Turnheim and Geels, 2012, p. 46). Importantly, it is the system or regime that is destabilized and undergoes large-scale change.

While earlier transition studies have drawn on the concept of destabilization to broadly reflect these elements (e.g., Elzen et al., 2004; Geels and Schot, 2007; Tukker, 2005), two more recent strands of research have explored the concept in greater detail (see Figure 6). The first is

[4] See https://www.lexico.com/definition/destabilization

principally concerned with understanding the process by which socio-technical regimes become destabilized and open to change, developing a processual model based on historical patterns. The second strand is somewhat more interested in identifying how policy might facilitate the destabilization process. These strands of work are deeply entwined, with a number of studies contributing to both. Indeed, results indicate that the literature contributing to destabilization is densely interconnected and largely coherent regarding theoretical perspective.

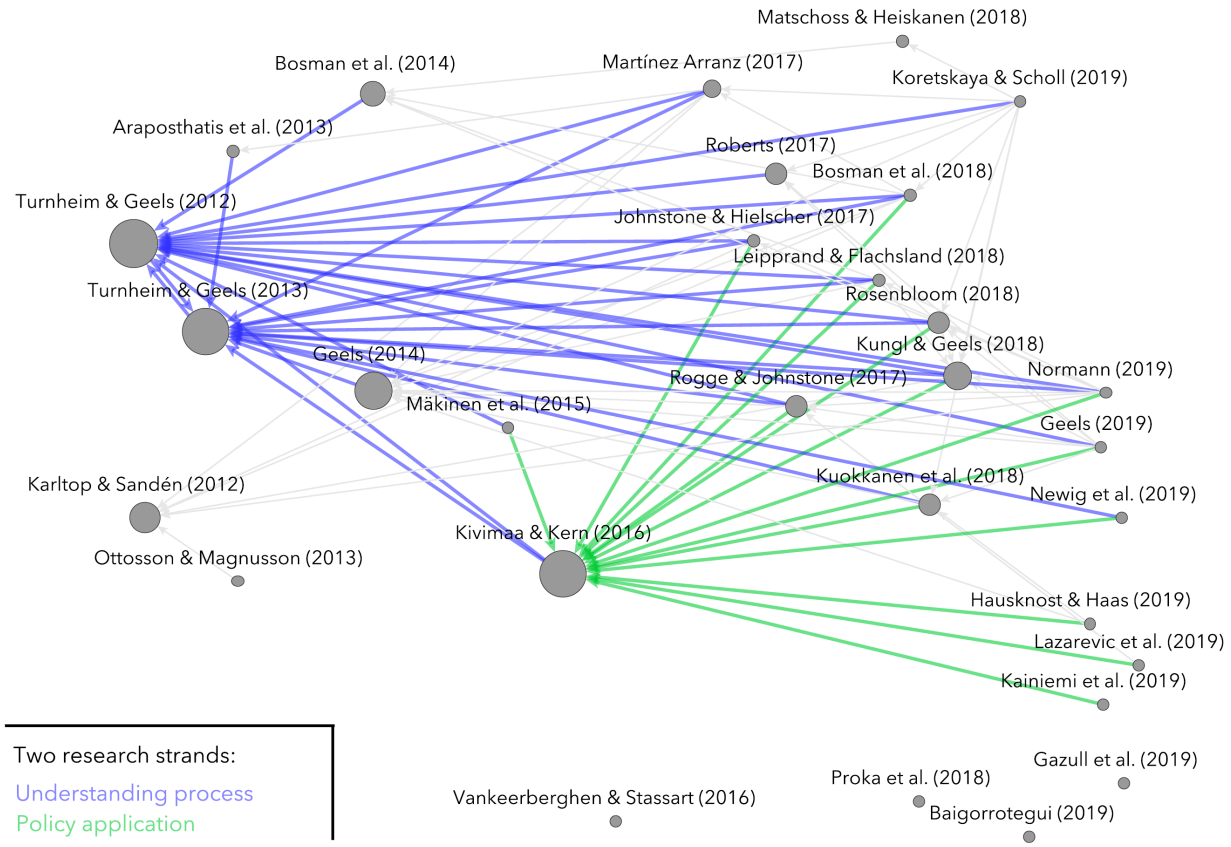


Figure 6: Citation network of scholarly work on destabilization
This figure maps the 30 texts captured by the survey and their referencing patterns. Arrows depict referencing patterns, with incoming arrows pointing at the text being cited (e.g., Kainiemi et al., 2019 cite Kivimaa & Kern, 2016). Node size is proportional to the number of incoming citations within the sample. Arrow color is explained in the figure legend.

With respect to the first strand, seminal work by Turnheim and Geels (2013, 2012) has more deeply elucidated the process of destabilization in sustainability transitions. Examining the historical downturn of the British coal industry, this research sees destabilization as a necessary precursor to the decline of a socio-technical regime (i.e., the flipside of transitions). As depicted in Figure 7, it is a coevolutionary process involving interactions among: (1) external pressures undermining the resources and legitimacy of the regime; and (2) responses by industry actors (e.g., weakened commitments to established arrangements). Destabilization arises from multiple sites of pressure, including from landscape factors, disruptive forces from niches, and issues internal to the regime. How and when these sites interact help define the specific patterns of destabilization that play out over several phases (Turnheim and Geels, 2012). Building on these insights, more recent work has expanded upon the political mechanisms (Geels, 2014), discursive

dimensions (Bosman et al., 2014; Leipprand & Flachsland, 2018; Roberts, 2017; Rosenbloom, 2018), and historical patterns (Kungl and Geels, 2018) marking destabilization.

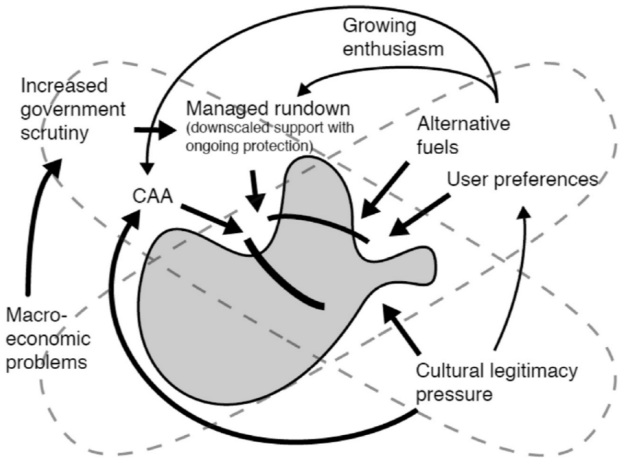


Fig. 13. Multi-dimensional pressures and spillovers (1957–1965).

Potential innovation/system influence of policy instrument
Destruction (regime destabilisation)
Control policies (D1)
Significant changes in regime rules (D2)
Reduced support for dominant regime technologies (D3)
Changes in social networks, replacement of key actors (D4)

Figure 7: Depictions of destabilization
The imagery associated with destabilization reflects the two core research strands. The image to the left is drawn from Turnheim & Geels (2013) and depicts the multidimensional pressures on a socio-technical regime (grey shape in the center) along with their attempts to adapt to these pressures. The table to the right is adapted from Kivimaa & Kern (2016) and lists the main functions policy can fulfill in destabilizing carbon-intensive systems.

A second strand explicates the central role of policy in destabilization. Drawing on Turnheim and Geels (2012) along with Schumpeterian creative destruction, Kivimaa and Kern (2016) see destabilization and innovation as mutually reinforcing processes, emphasizing the role of policy in unlocking these complementarities. They postulate that "policy mixes favourable to sustainability transitions need to involve both policies aiming for the 'creation' of new and for 'destroying' (or withdrawing support for) the old" (2016, p. 206). This work outlines four policy types that fulfill destabilizing functions: (1) control policies (e.g., technology bans or taxes), which put pressure on the regime; (2) significant changes to regime rules (e.g., nationalization), which fundamentally alter core logics and guiding principles; (3) reduced support for dominant technologies (e.g., removing fossil fuel subsidies), which erode the resources of the regime; and (4) changes in actor networks (e.g., changing decision-making venues), which dilute the influence of interests aligned with the regime. More recent work has proposed a fifth type: new organizational or institutional practices to support more coherent policy implementation (Kivimaa et al., 2017b). As Figure 6 indicates, these have been taken up by an array of scholars to map policy mixes in several unfolding transition contexts (e.g., Kainiemi et al., 2019; Lazarevic et al., 2019; Scordato et al., 2018).

Taken together, destabilization has come to form a central line of inquiry within research on sustainability transitions (Geels, 2019). While it is understood as a series of interacting pressures from multiple sites that play out in a phased fashion and open possibilities for dramatic change (Turnheim and Geels, 2012), it is also viewed as being a target for deliberate policy intervention (Kivimaa and Kern, 2016). In this way, destabilization is not only a core part of the low-carbon

transition process but also a way to help accelerate such processes. Despite the importance of this concept in transition research, it has yet to gain significant traction in political or policy domains. Even so, there is now growing interest among the policy community to engage with transition ideas (Asquith et al., 2017; Victor et al., 2019), which may facilitate its uptake as a problem frame for the practical challenge of consciously managing the decline of carbon-intensive systems.

4. Deliberate decline: a comparative discussion

Our analysis has explored the concepts of phase-out, divestment, and destabilization, revealing that each reflects diverse core meanings and models of decline in the context of decarbonization (see Table 1). Underpinned by distinct roots and practical applications, each also foregrounds varying units and drivers of decline. According to our findings, phase-out has principally been advanced by communities of policy and practice as a regulatory approach that actively seeks the orderly termination of fossil fuels in general or specific carbon-intensive technologies, infrastructures, and processes. This concept frames decarbonization as deeply linked to the role of physical assets and supporting infrastructures, placing emphasis on public policy in managing the elimination of these elements. In contrast, divestment has mainly arisen from civil society and takes the character of a movement, strategy, and discourse aiming to erode the position of fossil fuels in political, financial, and energy systems. This concept paints the fossil fuel industry as the core of the problem, confronting the financial resources and political power of these interests. While policy remains important, broader groups of actors are given particular weight through their investment decisions and political activities. The concept of destabilization, finally, has been taken up by transition scholars to embrace the process that upsets the stability of a carbon-intensive system and opens it to change along with the functions policy can fulfill to facilitate the breakup of such systems. Adopting an encompassing view, destabilization stresses the deep embeddedness of fossil fuels within socio-technical systems, requiring that multiple lock-ins are simultaneously weakened. Policy is seen as central, but many other drivers also play a role. Overall, our analysis suggests that while each of the three concepts engages with somewhat different dimensions of decline and is based on different assumptions about how it might unfold in relation to decarbonization, there are important intersections among them. In this fashion, despite asymmetries, these concepts and the research strands that animate them offer complementary ways of contemplating intentional decline as part of the pursuit of decarbonization.

Table 1: Juxtaposition of concepts engaging with deliberate decline

	Phase-out	*Divestment*	*Destabilization*
Roots	Policy	Civil society	Transition scholarship
Practical applications	Policies targeting coal-fired power, combustion automobiles, oil/gas heaters, incandescent bulbs, etc…	Climate activism and investment strategies	Growing interest among policy community but more limited uptake to date
Core meaning	A policy approach that actively seeks the termination of a specific technology, substance, or process that causes negative externalities	A movement, strategy, and discourse that seeks to erode the position of fossil fuels in political, financial, and energy systems	A process that upsets the stability of a carbon-intensive system and opens it to change along with the functions policy can fulfill to facilitate this
Model of decline	Managed and gradual or stepwise process, usually targeting a specified end date and unfolding over an extended period of time (up to decades)	Weakening position of fossil fuel interests opens up possibility of transformative change	Interacting external and internal pressures along with actor responses create the opportunity for system change
Unit undergoing decline	A technology, process, or substance	Financial resources and political position of fossil fuel industry	Socio-technical system or regime
Drivers of decline	Emphasis on deliberate regulatory intervention by the state; still questions about role of markets	Tendency to emphasize investment decisions of non-state actors	Multi-actor process but also key role for policy intervention

There is already some cross-fertilization among the communities invoking these concepts, with a number of studies contributing to the development of more than one concept (see Figure 8). In particular, recent work on phase-out tends to draw from seminal works on destabilization. In this way, phase-out is sometimes regarded as intertwined with processes of regime destabilization and as a critical part of policy mixes stimulating decarbonization pathways (Kivimaa and Kern, 2016; Rogge and Johnstone, 2017; Rosenbloom, 2018). Works on phase-out also draw from perspectives on divestment but to a more limited extent, calling attention to divestment as a potential factor encouraging the adoption of phase-out policies (e.g., Trencher et al., 2019). Yet, cross-referencing between works on divestment and phase-out remains sparse, suggesting that there may be additional opportunities to explore complementarities among phase-out and divestment in orienting deliberate decline. There is even less cross-fertilization between the divestment and destabilization literatures, which may be fruitful terrain for future research (e.g., exploring the role of climate activist networks in regime destabilization or adopting a more explicitly systemic approach to study divestment).

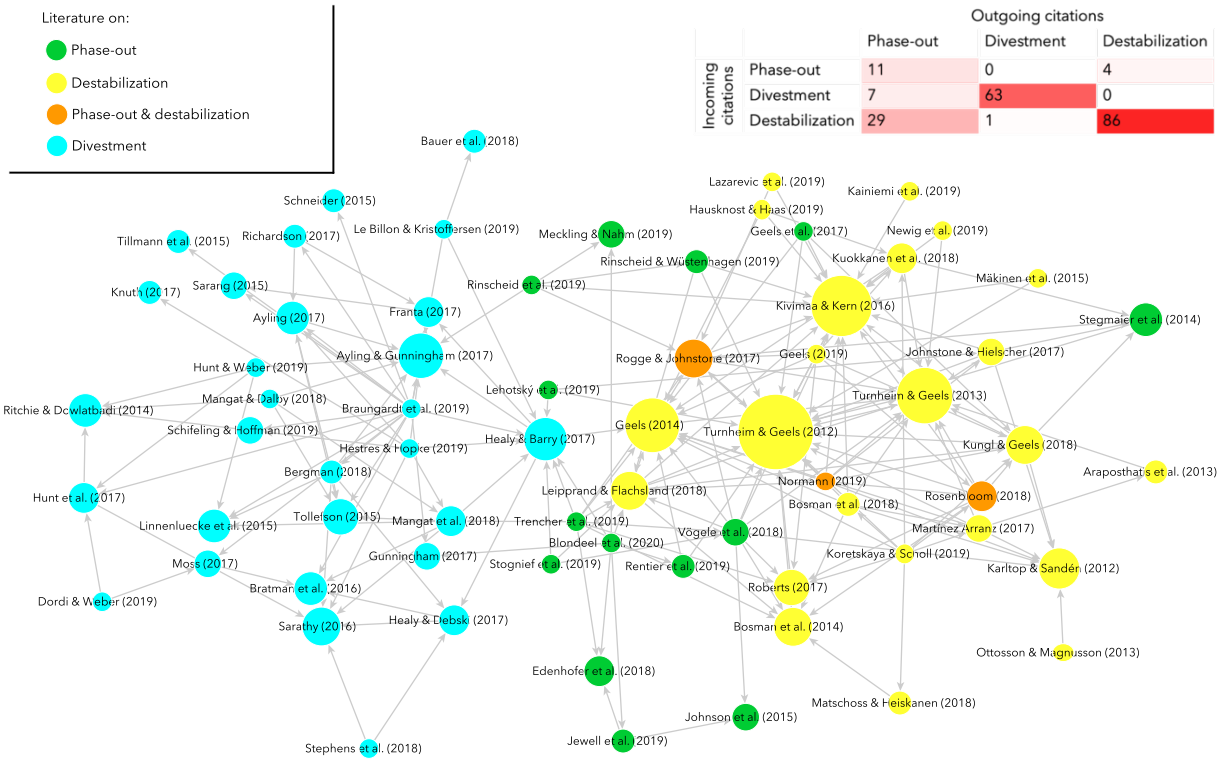


Figure 8: Citation network of studies on phase-out, divestment, and destabilization in the context of decarbonization

This image depicts the aggregated citation network based on Figures 2, 5 and 6. Arrows indicate referencing patterns, with incoming arrows pointing at the text being cited (e.g., Richardson, 2017 cites Franta, 2017). Node size is proportional to the number of incoming citations within the network. Node color is explained in the figure legend. Isolates and isolated dyads are omitted from the graph. The table in the top right indicates citation counts within and across the literatures contributing to the development of each concept. For the table in the top right, the three texts included in both reviews of phase-out and destabilization were assigned to destabilization.

To date, there is a marked imbalance with respect to the prominence of these concepts in policy and practice surrounding decarbonization. Phase-out represents the dominant way in which decline is approached in policy communities, holding appeal among the public and decisionmakers as an effective and coherent regulatory approach to address decarbonization. This has the inadvertent implication of reducing the challenge to one of technologies and infrastructures along with overemphasizing the place of policy as a driver of change. Divestment has, on the other hand, helped activate and orient diverse networks of societal actors. Although it has empowered climate activists and campus communities, it has also helped motivate various types of investors concerned not only with climate but also with the risk of stranded fossil fuel assets and the long-term return on their investments. Nevertheless, orienting climate responses too closely according to this concept may overstate the importance of finance in stimulating decline. Representing one of the broadest ways to approach deliberate decline, destabilization has only recently garnered interest among policy communities. While the system perspective it offers may help appreciate the depth of the challenge, framing efforts in terms of this concept may also be of limited appeal to decisionmakers whose political prospects often rest on maintaining

stability and reducing complexity. Discussing these concepts in relation to various sources of carbon lock-in, we attempt to gain traction on the overarching character of deliberate decline as well as its implications for future research and practice.

5. Future directions for research and practice

Our findings suggest that, in the context of decarbonization, deliberate decline can be understood as *the managed erosion of lock-ins that perpetuate the production and consumption of fossil fuels*. Societal engagement around decline would, therefore, begin with identifying and targeting such lock-ins. Returning to the three general sources of lock-in raised in the introduction (techno-economic, political-institutional, and behavioral), we sketch the role of decline, interactions with innovation, and potential directions for research and practice.

Techno-economic lock-ins relate, in particular, to the long lead times, large sunk costs (in physical and human capital), and experience accumulated around fossil fuel technologies and supportive infrastructures. Work on phase-out suggests that regulatory or other policy approaches show promise in targeting this lock-in, whereas research on divestment underscores that the financial flows underpinning these material elements must also be eroded. Yet, equal attention must be paid to interactions with innovation: investment patterns need to be reoriented toward low-carbon innovation (e.g., through divest-invest strategies) rather than simply diverted away from fossil fuels; and carbon-intensive arrangements (e.g., coal-fired power plants) must be replaced with low-carbon alternatives (e.g., wind and solar) instead of other fossil fuel-based sources that are only slightly less carbon-intensive (e.g., natural gas). Future research and policy efforts in this area may specifically focus on the decline-innovation nexus (see Rogge and Johnstone, 2017), concentrating on the timing, sequencing, and interaction of decline and innovation initiatives. Related questions for research and practice also surround: the way in which signaling a technology phase-out impacts innovation processes; the role of industrial policy in accelerating the decline of carbon-intensive arrangements and unlocking desirable futures (Meckling and Nahm, 2019); how regions that are disproportionally affected by phase-outs (e.g., coal industry communities) might be supported or even encouraged to become clean innovation frontrunners (Edwards, 2019; Johnstone and Hielscher, 2017); and how public support for phase-outs can be maintained in the face of political challenges such as the rise of right-wing populism (Lockwood, 2018).

Political-institutional lock-ins involve the rulesets and political systems that have co-evolved alongside the use of fossil fuels and continue to sustain their consumption. From technology standards to market rules to procurement guidelines, carbon-intensive technologies and practices tend to receive privileged consideration. Research suggests that these frameworks are sustained by entrenched carbon-intensive interests given their hold over decision-making processes (Geels, 2014; Hess, 2014; Meckling, 2015; Wettestad, 2009). Destabilization points to the importance of profoundly reworking institutional arrangements. And, both destabilization and divestment indicate that the alliances between the fossil fuel industry and government must be severed in order to create the conditions for transformative innovation. While some have suggested that this might be accomplished by shifting decision-making venues so as to favor alternative guiding principles (e.g., placing greater authority for energy investment with local communities) or rebalancing advisory boards to remove fossil fuel representatives (Kivimaa and Kern, 2016), disentangling carbon-intensive considerations from multiple societal domains and activities (from politics to science to the arts) demands greater attention in future research and practice.

Associated directions include: the extent to which incumbent actors and institutions might be renewed, reoriented, or displaced in order to drive pathways to decarbonization (Turnheim and Sovacool, 2019); how linkages among fossil fuel interests across multiple geographic scales and contexts might be weakened (Fuenfschilling and Binz, 2018); the ways in which communities resisting fossil fuel development (e.g., many Indigenous Peoples) or championing low-carbon alternatives (e.g., energy cooperatives) might be further networked and empowered to become increasingly relevant political veto players (Burke and Stephens, 2017; McAteer and Pulver, 2009); how initiatives to disentangle fossil fuel interests from decision-making processes and institutions might be made resilient (Bernstein and Hoffmann, 2018; Jordan and Matt, 2014; Rosenbloom et al., 2019); and how new modes of governance (based, for example, on experimentation and networks) may erode lock-ins and accelerate the diffusion of innovations (Bäckstrand, 2008; Bulkeley et al., 2012; Kivimaa et al., 2017a; Sengers et al., 2019; Tosun and Schoenefeld, 2017).

Behavioral lock-ins relate to individual decisions and practices along with their interactions with social forces (e.g., social norms) that, together, help (re)produce carbon-intensive arrangements. While behavioral economists have investigated a broad range of interventions such as nudges to overcome this type of lock-in (Stern, 2020), the regulation of carbon-intensive practices may ultimately be needed (as is the case for vehicle idling in many municipalities, for instance). Indeed, individual lifestyles are sustained by longstanding cultural forces, routines, and discourses that can be difficult to unravel (Sheller and Urry, 2002). Both destabilization and divestment underscore the importance of developing new problem frames and discourses that delegitimize current carbon-intensive patterns, driving home the consequences of current arrangements. Consider, for instance, how behavior around waste has changed markedly over the past several decades, thanks in part to sustained anti-littering campaigns by nongovernmental organizations which popularized the term ‘litterbug’ in North America (Melosi, 1981). Yet, compelling narratives and positive frames are also needed to erode lock-ins and reorient practices toward desirable alternatives (Buschmann and Oels, 2019; Robinson and Cole, 2015). Consider, for instance, how ‘we recycle’ became a powerful storyline and motivator in the waste context. In this way, the formation, adaptation, and interaction of (de)legitimizing narratives represent critical directions for future research and practice. This might involve identifying how promising delegitimizing narratives emerge and take hold, connect with positive visions, and encourage changes in lifestyles among societal actors. And, as part of this, there is also merit in contemplating how these discourses can be complemented by policy efforts to break vicious cycles of environmentally damaging behavior and unleash tipping points promoting desirable lifestyle change such as has occurred around smoking in many jurisdictions (Nyborg et al., 2016).

Beyond targeting the abovementioned lock-ins, our findings have three important implications for the pursuit of decarbonization. First, it is clear that portfolios of policies and societal initiatives are a defining characteristic of decarbonization efforts given the multiple and mutually reinforcing points of lock-in across political and economic systems, which require new approaches and interacting measures (Kern et al., 2019). Thus, we caution against heeding calls for uniform or unitary climate policy – as is sometimes the case for carbon pricing. Second, and relatedly, interactions among policies are even more important than previously considered given the need to unlock complementarities among decline and innovation related efforts. This may involve, for instance, closely considering the timing and sequencing of measures promoting decline so that they create space for emerging alternatives at particular moments rather than

leading society along dead end paths. Finally, our analysis suggests that there is also a need to further broaden the orientation of research and practice to embrace deliberate decline. Further engagement will be needed to uncover the many other potential dimensions of decline beyond those identified here and to gain further traction on the implications such an orientation suggests for decarbonization.

Appendix

Our data collection and sampling strategy is depicted in Figure A1.

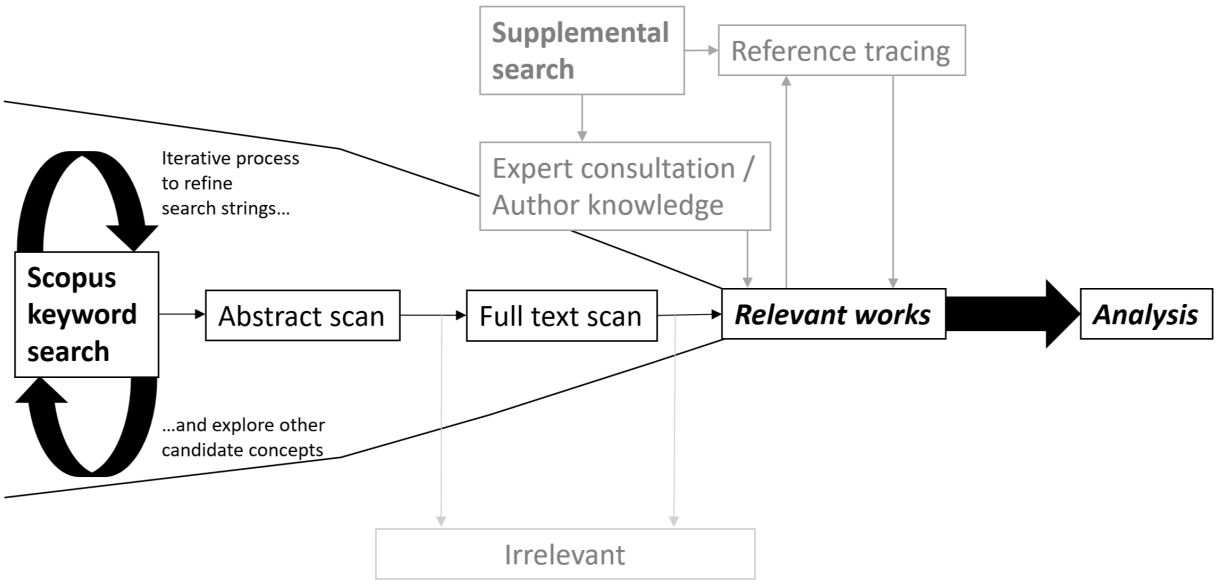


Figure A1: Data collection and sampling strategy

The following keyword search strings were used to capture sources from the SCOPUS database for each of the selected concepts.

Phase-out: TITLE-ABS-KEY (phaseout OR phase-out AND ban* OR government OR policy OR subsid* AND "climate change"). This search returned 106 hits (as of January 13, 2020). A close review of all abstracts (and full texts for edge cases) was conducted to determine if these were in scope and dealt substantively with phase-out. From this, 20 were identified as particularly relevant. These sources were subjected to a full reading and in-depth analysis. This search was supplemented by 17 additional texts, which were identified by examining works referenced within the above sources and based on the knowledge of the authors.

Divestment: TITLE-ABS-KEY (divestment) AND TITLE-ABS-KEY ("fossil fuel") AND TITLE-ABS-KEY ("climate change"). This search returned 44 hits (as of December 5, 2019). A close review of all abstracts (and full texts for edge cases) was conducted to determine if these were in scope and dealt substantively with divestment. From this, 31 were identified as particularly relevant. These sources were subjected to a full reading and in-depth analysis. This search was supplemented by 1 additional text, which was identified by examining works referenced within the above sources.

Destabilization: TITLE-ABS-KEY ("destabilization") OR TITLE-ABS-KEY ("destabilisation") AND REF (geels) OR REF (hekkert) OR REF (loorbach). This search returned 41 hits (as of October 11, 2019). A close review of all abstracts (and full texts for edge cases) was conducted to determine if these were in scope and dealt substantively with destabilization. From this, 27 were identified as particularly relevant. These sources were subjected to a full reading and in-depth analysis. This search was supplemented by 3 additional texts, which were identified by examining works referenced within the above sources and based on the knowledge of the authors.

The following Scopus keyword search strings were used to explore other potential concepts of interest, though these were found to be somewhat less prominent than the concepts selected for in-depth review.

Exnovation: TITLE-ABS-KEY (exnovat* AND "climate change" OR decarbonization OR decarbonisation OR governance). This search returned 4 hits (as of January 13, 2020). A close review of all abstracts (and full texts for edge cases) was conducted to determine if these were in scope and dealt substantively with exnovation. All 4 texts were identified as relevant.

Discontinuation: TITLE-ABS-KEY (discontinuation AND "climate change" OR decarbonization OR decarbonisation OR governance). This search returned 43 hits (as of January 13, 2020). A close review of all abstracts (and full texts for edge cases) was conducted to determine if these were in scope and dealt substantively with discontinuation. From this, 3 were identified as relevant.

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