The politics of decarbonization pathways:

Responses, conflicts, and the transition to a low-carbon energy future

by

Daniel Rosenbloom

A thesis submitted to the Faculty of Graduate and Postdoctoral Affairs

in partial fulfilment of the requirement for the degree of

Doctor of Philosophy

in

Public Policy

Carleton University

Ottawa, Ontario

Abstract

This thesis explores the politics of decarbonization pathways, with a particular focus on the responses to and conflicts surrounding the transition to a low-carbon energy future. As part of this, the dissertation: (1) scrutinizes how the concept of "pathways" is understood within climate-energy policy and analysis; and (2) attends to the struggles involved in pursuing potential pathways to carbon-neutral energy systems. Two overarching and interrelated research questions orient this work. First, how are pathways understood in the context of the low-carbon transition? And second, how are the socio-technical responses that help make up these pathways contested and shaped through politics?

The introductory chapter of this thesis lays the groundwork for interrogating these questions, providing background on the subject of climate change, outlining the role of energy in this challenge, raising issues around the governance of low-carbon transitions, identifying research aims and questions, and discussing relevant research perspectives and approaches. Drawing on transition and discursive perspectives, chapters 2 through 4 then present three studies that take up the research questions by exploring different political aspects of decarbonization pathways. A concluding chapter reflects on the contributions of this work and potential future directions.

The three studies forming the core contributions of this dissertation have been published in peer-reviewed academic journals. The first article elucidates the way in which diverse actors construct meaning around the concept of "pathways" in the context of the low-carbon transition. The second article uncovers ideational conflicts surrounding a historical episode of low-carbon change: the phase-out of coal-fired power in Ontario. The third article reveals tensions and

alignments around an unfolding episode of low-carbon change: how different energy systems (electricity, transport, and heating) and their affiliated actors are interacting around expanded societal electrification and electricity trade. Broadly, the three papers developed here underscore that *ideas matter in transitions*. These ideas relate not only to the concepts and categories used to frame the climate challenge (such as "pathways") but also the narratives linked to possible responses (alternative innovations and institutional arrangements) that are advanced by contending interests.

Acknowledgements

I would like to acknowledge the financial support of the Social Sciences and Humanities Research Council, Ontario Graduate Scholarships, and Carleton University. Without the support of the federal and provincial funding agencies as well as my home institution, this endeavor would not have been possible.

I have also benefitted from the intellectual and emotional support of a great many people. I am first and foremost indebted to my supervisor, Professor James Meadowcroft, not only for his continuous and helpful feedback on my work but also for encouraging me to transcend my limits. Much is owed to his guidance for my professional and personal development over the course of my doctoral studies and our many collaborations. His curiosity, excitement, and rich knowledge have stimulated and inspired me. Even in the face of pressing deadlines and numerous commitments, he has been generous with his time and ideas. It was quite simply a joy to work closely with him and I could not have hoped for a better supervisor.

My committee also served as a critical support for this research undertaking. Professors Alexandra Mallett and Glen Toner were essential resources and mentors throughout the research process. I am incredibly grateful for their words of encouragement as well as constructive criticisms, in equal measure. Their insightful comments have been instrumental in guiding my research choices and crystallizing my ideas. Beyond intellectual and research guidance, they have also been wonderful and supportive colleagues. I've learned as much in the company of the brilliant minds at 'Table 101' as in the classroom.

The supportive staff and faculty of the School of Public Policy and Administration have also facilitated this journey. The classes taught by Professors Stephan Schott, Frances Abele, Graeme Auld, Manfred Bienefeld, and Jennifer Stewart helped me carve out my vision for this thesis. I am particularly grateful to Professor Saul Schwartz, former PhD program supervisor, for helping me refine my initial research proposal in the Doctoral Research Seminar of 2015. My fellow PhD students, especially those in my cohort, were instrumental throughout this process.

There are also many to thank outside of the Carleton community. First and foremost, the members of the Ontario Network for Sustainable Energy Policy have been a great help over the years. Their constructive comments at the annual workshop have been especially useful in guiding my revisions. I am also grateful to the participants of the International Sustainability Transitions Conference for their insightful feedback on my first paper. Moreover, the comments of the editors and anonymous reviewers at Global Environmental Change, Environmental Innovation and Societal Transitions, and Energy Research & Social Science were integral in strengthening the papers that make up this thesis.

On the personal front, I would like to thank my lovely and talented wife, Robyn Carson. She embarked upon her own PhD journey in 2011 and completed it in 2018, making her both my guide and companion on this path. Her constant presence, support, encouragement, and constructive feedback have kept me on course. My daughter, Meera, also joined us on this journey in May 2018. Lastly, I would like to thank my immediate family and friends for their unending patience and support.

Table of contents

List of tables

List of figures

List of appendices

Chapter 1 – Introduction

This thesis explores the politics of decarbonization pathways, with a particular focus on the responses to and conflicts surrounding the transition to a low-carbon energy future. A credible effort to address climate change will require a relatively rapid low-carbon transition in the energy systems underpinning modern societies (IPCC, 2014a). This entails transformative adjustments to social, political, economic, and technological arrangements (Geels et al., 2017a). Over the past two decades, the concept of pathways has emerged as an increasingly important way to frame this societal challenge and contemplate the multiple dimensions of change associated with long-term movement toward decarbonization (Turnheim et al., 2015; Wiseman et al., 2013). However, to date, there is limited consistency in the use of this concept as a critical problem frame or analytical device. Moreover, while a considerable body of work emphasizes the technological and geophysical dimensions of decarbonization pathways, somewhat less has been done to engage with the political domains underlying this transformative pursuit.

In response, this dissertation: (1) scrutinizes how the concept of "pathways" is understood within climate-energy policy and analysis; and (2) attends to the struggles involved in pursuing potential pathways to carbon-neutral energy systems. Two overarching and interrelated research questions orient this work. First, how are pathways understood in the context of the low-carbon transition? And second, how are the socio-technical responses that help make up these pathways contested and shaped through politics?

To address these questions, the thesis draws upon insights from transition studies and complementary discursive perspectives. Transition research provides a useful lens through which

to view the climate challenge as it calls attention to: (1) the interconnected role of social and technical (socio-technical) factors involved in long-term processes of systems change, (2) the multidecadal nature of these processes, (3) the forces of continuity that promote movement in a carbon-intensive direction, and (4) the potential drivers of transformative change within societal systems such as transport or electricity (Grin et al., 2011a). Discursive perspectives, on the other hand, can enrich transition perspectives by more closely examining the political dynamics that underlie processes of fundamental change in societal systems, uncovering the conflicts over ideas the are central to defining policy problems and identifying appropriate responses (Fischer and Forester, 1993). In this fashion, transition and discursive perspectives can together provide a more complete picture of interacting political domains (ideas, institutions, interests, along with innovations and infrastructures) in low-carbon energy transitions, revealing how actors actively use *ideas* to influence policy responses (commitments about *institutions* as well as *innovations* and *infrastructures*, in particular) in such a way as to reinforce their perceived *interests*. These two theoretical traditions inform the research approach and analytical orientation adopted in the three studies that make up the core of this thesis.

These three studies each respond to one or more of the research questions outlined above. The first study, entitled "Pathways: an emerging concept for the theory and governance of low-carbon transitions" and published in *Global Environmental Change*, examines the way in which diverse actors construct meaning around the concept of "pathways" in the context of the low-carbon transition. It carries out a survey of the relevant climate change mitigation literature. The study finds three core conceptions of pathways linked to diverse perspectives and approaches, each of which emphasizes different yet interconnected dimensions of the decarbonization

challenge: biophysical, techno-economic, and socio-technical. It also identifies the pitfalls and promise of the concept in contemplating the low-carbon transition, suggesting that there is room to further engage with the politics underlying this process. Informed by this effort, the second study, entitled "Framing low-carbon pathways: a discursive analysis of contending storylines surrounding the phase-out of coal-fired power in Ontario" and published in *Environmental Innovation and Societal Transitions*, explores political dynamics surrounding a historical episode of low-carbon change: the phase-out of coal-fired power in Ontario. Through an analysis of media articles, it elaborates the conflicts over ideas that mark this experience. The study reveals the way in which contending actors frame issues and technologies, modulating possibilities and shaping the sequences of choices that link current societal arrangements to future low-carbon states. The third study, entitled "A clash of socio-technical systems: exploring actor interactions around electrification and electricity trade in unfolding low-carbon pathways for Ontario" and published in *Energy Research & Social Science*, explores political dynamics surrounding an unfolding episode of low-carbon change: how different energy systems (electricity, transport, and heating) and their affiliated actors are interacting around expanded societal electrification and electricity trade. To shed light on this, the study carries out an analysis of the actor positions articulated during the 2017 Long-term Energy Plan consultation in Ontario. Findings indicate that emerging interactions around electrification of transport are marked by less conflictual patterns in Ontario, whereas electrification of heat and electricity trade are characterized by deeper frictions.

These three studies generate a series of interconnected insights for the theory and governance of low-carbon transitions. Responding to the research questions and objectives, two core

contributions are distilled here. First, this program of research elucidates the way in which diverse constituencies construct meaning around pathways in order to contemplate and respond to the low-carbon transition. Second, this work elaborates how the socio-technical responses that help make up pathways are contested and shaped through politics. In particular, the three papers developed here underscore that *ideas matter in transitions*. According to this research, ideas relate not only to the concepts and categories used to frame the climate challenge (e.g., "pathways" or "resilience") but also the storylines linked to possible responses (e.g., phasing out coal). Attending further to ideas is an important way to gain traction on the political domains of transitions (elaborated in Section 4) and understand how these domains interact to shape alternative low-carbon trajectories. In essence, ideas help define the climate change problem, constitute the envelope of possible solutions, and animate conflicts among contending actors and interests. And so, in the context of profound complexity and uncertainty, struggles over ideas are of central importance in determining the pace and character of low-carbon transitions: how might societal systems operate in the future, through what means and at what pace will systems move toward these futures, which innovations and actors will be given prominence in these journeys, and who will ultimately win or lose.

The thesis is organized as follows. Chapter 1 is composed of an introductory essay. This essay provides background on the subject of climate change, raises a number of important issues facing the governance of this challenge, identifies the research questions, and discusses key theoretical and research approaches that inform the three studies making up the dissertation. Chapters 2 through 4 then move to present the three studies. In Chapter 5, the thesis concludes by taking stock of the core contributions and reflecting upon future research directions.

1. The climate challenge

1.1 Climate change and the role of energy

There is overwhelming scientific evidence that human activities, particularly the combustion of fossil fuels for the provision of energy services such as transportation and electricity, are altering the global climate through the release of greenhouse gas (GHG) emissions (IPCC, 2013). This climate challenge is in large part an energy problem given that energy accounts for over 70% of anthropogenic GHG emissions (C2ES, 2017). With the increasing reliance on fossil fuels to drive modern industrial economies, atmospheric concentrations of GHGs have risen from well below 300 parts per million of CO2-equivalent during the pre-industrial era to over 400 parts per million in 2018 (NASA Global Climate Change, 2018). Despite mounting efforts to reverse this trend, annual energy-related GHG emissions have continued to rise, reaching a record high of 32.5 gigatons in 2017 (International Energy Agency, 2018). The past and present release of GHG emissions is already beginning to drive up global temperatures and destabilize the climate system, which is leading to more extreme weather events, receding glaciers, and sea level rise (Fischer and Knutti, 2015; Marzeion et al., 2014). Research suggests that the anthropogenic release of carbon into the atmosphere has fundamentally reshaped the natural world (Raupach and Canadell, 2010) and begun to exceed critical planetary thresholds (Steffen et al., 2015). Climate science indicates that the continuation of this carbon-intensive course of societal development over the next decades is likely to produce a global temperature rise from 3.2°C to 5.4°C by 2100 (Fuss et al., 2014). According to the IPCC (2014b), this can be expected to unleash severe impacts ranging from increased droughts and floods, extreme heat and wildfires, sea level rise and mass migration, to the collapse of both ecologically and economically

significant biophysical systems such as fisheries and forests. Taken together, the emerging and future impacts of climate change not only pose a serious threat to natural systems but also undermine the prospects for human prosperity.

In response, international political leaders have affirmed the importance of averting the most severe impacts of climate change by "holding the increase in the global average temperature to well below 2°C above pre-industrial levels" (United Nations Framework Convention on Climate Change, 2015, p. 3). Climate science indicates that adhering to this temperature limit involves curtailing atmospheric concentrations of CO2-equivalent emissions to about 450 parts per million by 2100 (IPCC, 2014c). With this, annual GHG emissions would need to peak around 2020 and decline substantially thereafter to what is essentially carbon neutrality by the end of the century.

Correspondingly, research points to an equally significant shift in energy sources and technologies that would accompany such a decline. Prominent forward-looking perspectives highlight: the need for low-carbon energy sources to play a dominant (roughly 80%) role in meeting global transport and electricity demand by 2050 (Riahi et al., 2012); the technical and economic feasibility of displacing conventional energy sources with emerging renewable energy technologies (Jacobson et al., 2015); and the increasing centrality of extreme technological solutions such as carbon dioxide removal – bioenergy with carbon capture and storage – in extending the horizon for near-term climate responses and the potential for safely reaching temperature targets (Rogelj et al., 2015; van Vuuren et al., 2013). In essence, energy models point to a nearly wholesale reconfiguration of electricity, transport, industry, and building

systems. One element of this reconfiguration is the rapid decline of fossil fuels that do not utilize carbon capture and sequestration. A second element relates to the radical rise of fuel switching (e.g., natural gas heating to electric heating), alternative energy sources (e.g., new renewables), as well as conservation and efficiency (e.g., behavioral adjustments and building retrofits).

Even now tremendous investment in low-carbon renewable energy technologies such as wind and solar is being made, with outlays peaking in 2015 at $323.4 billion and annual installed capacity reaching a record 157 gigawatts in 2017 (Bloomberg New Energy Finance, 2018). Although market forces have certainly played a role in this trend, public policy interventions hold a central place in spurring low-carbon investment (REN21, 2017) – one that is expected to continue if global targets are to be met (Figueres et al., 2017). Governments at all levels have taken steps to put in place climate plans and specific measures to reduce GHG emissions (Wiseman et al., 2013), with support for new renewable energy sources appearing prominently among these actions (Jacobsson and Lauber, 2006; Stokes, 2013). Yet, while investment and deployment trends might appear promising, far more will need to be done as fossil fuels continue to meet nearly 80% of final global energy consumption (REN21, 2017). Clearly, it will become increasingly important to accelerate low-carbon innovation and diffusion trajectories in the energy sector in order to drive down emissions in a manner consistent with climate targets and aspirations.

2. The transition to a low-carbon energy future

2.1 What is a low-carbon transition?

The changes that mark the shift to a low-carbon future are, however, not confined to technological advancement. Indeed, changes will pervade and fundamentally reshape interlinked societal arrangements (Foxon, 2011). Transformative changes will be required as carbon-intensive energy systems relying on fossil fuels have persisted for multiple decades and have come to underpin the development of modern economies and lifestyles. According to Smil (2016), fossil fuel sources represent a cornerstone of present-day human civilization and will only be replaced over a protracted period of technical and social change given the scale at which they have penetrated every aspect of society. Consider, for example, how: the design of cities and norms about travel have developed alongside the diffusion of the gas-powered automobile (Geels, 2005a; Sheller and Urry, 2002); notions of comfort have become entwined with energy-intensive indoor heating and cooling (Shove et al., 2014; Walker et al., 2014); the manufacture of products has come to rely on petrochemicals such as plastics (Center for International Environmental Law, 2017); and, important political and economic interests have cemented around fossil fuel-based resource exploitation (Haley, 2011) and electricity generation (Turnheim and Geels, 2012).

Taken together, a rich body of research suggests that the present carbon-intensive manner in which energy is produced and consumed has become deeply embedded within social and economic structures as well as inextricably intertwined with longstanding interests, norms, and practices (Geels and Schot, 2007; Smith et al., 2005). Considering the extent of this embeddedness, movement toward low-carbon energy systems implies multiple decades of transformative change spanning technological innovation trajectories but also lifestyles, business

models, institutional structures, as well as economic and political arrangements. Prominent research calls for no less than a *low-carbon transition*, encompassing the long-term processes of fundamental social and technical change consistent with moving toward decarbonized societies (Geels et al., 2017a).

A low-carbon transition refers to the way in which societal systems such as electricity and transport could move from carbon-intensive configurations to low-carbon arrangements over time. It implies modifications to the dominant 'way of doing things' that embraces not only technologies (e.g., the shift from gas-powered automobiles to electric vehicles) and infrastructures (e.g., fueling stations to charging stations) but also institutions (e.g., new policies to make up for lost government revenue from gasoline taxes), practices (e.g., changing behavior around travel to align with electric vehicle battery ranges), actors (e.g., a larger role for electric power providers in transport systems), and so on (Geels, 2004). That is, transitions are understood to be *socio-technical* in nature and concern the way in which basic societal functions are met (i.e., the societal provisioning of transport or heat) rather than more confined disruptions (e.g., at the level of the firm or supply chain).

According to historical studies, transitions involve multiple decades of co-evolutionary changes in technology and society (see Martínez Arranz, 2017) that cannot be reduced to a single driver given the scale and scope of the systems undergoing change (Geels and Kemp, 2007). Rather, there are multiple drivers and complex feedbacks that open up transformative directions of change (Roberts et al., 2018). Take, for instance, the historical transition from horse-based transportation to gas-powered automobiles (see Geels, 2005). This shift was spurred not simply

by technological innovation around the internal combustion engine but also by business model innovation (e.g., the mass-production and mass-market focus of the Ford Model T), changes in cultural norms (e.g., mounting health concerns surrounding horse manure), and, perhaps most importantly, institutions (e.g., policies promoting the adoption of the automobile over alternatives). Government played an integral role in building out paved streets and highway systems, redefining streets as places for high-speed private travel rather than public gatherings and encouraging suburbanization through urban planning. The layering of interacting social and technical factors also marked transitions in oceanic shipping (Geels, 2002), mass production (Geels, 2006), and hygiene (Geels, 2005b), among many others (Martínez Arranz, 2017; Papachristos et al., 2013).

2.2 Why is policy needed and why is it particularly difficult?

Historical episodes of system change were, however, far from entirely conscious or deliberate affairs. These experiences were to a large extent marked by a layering of context-specific and historically contingent processes, along with the accumulation of choices and consequences (both anticipated and unanticipated) over time. While contingency and unintended consequences will also help shape the unfolding low-carbon transition, it must be a more conscious and deliberate societal project with policy acting as a central driver in promoting change at a pace consistent with averting the worst impacts of climate disruption (Kern and Rogge, 2016). And, given the scope of the climate challenge (fossil fuels underlie nearly every aspect of modern life), the profound social and technological changes needed to reorient society toward decarbonization cannot be left to markets alone.

This understanding is reflected across the literature, with research spanning diverse disciplinary perspectives placing great emphasis on the importance of climate policy frameworks in enacting low-carbon change. There is, for instance, wide agreement among economists that a broad-based price on GHG emissions will be central to promoting the necessary changes in technology, individual behavior, and business investments (Beugin et al., 2018; Howard and Sylvan, 2015; Stiglitz and Stern, 2017). Others propose that a range of policy measures such as regulatory instruments (e.g., the phase-out of coal or specific standards for low-carbon energy sources), technology support (e.g., research and demonstration funding for novel low-carbon possibilities), and sector-specific incentives (e.g., above-market rates for electricity from new renewables) will also be critical in accelerating innovation processes and bringing about a low-carbon transition (Jaccard, 2016; Kivimaa and Kern, 2016; Rogge et al., 2018). Even though there is much disagreement about what might constitute an appropriate policy response (e.g., the weight given to carbon pricing versus regulation or the level of a carbon price), there is nevertheless a growing consensus among experts that public policy at all levels will need to play a leading role in adjusting practices, technologies, business models, and rule systems in order to realize a low-carbon future.

Despite a recognition of the need for deliberate and conscious action, there are a variety of reasons why climate change poses a particularly difficult (or even 'super wicked') policy problem (Levin et al., 2012). Although distinct analyses and perspectives may highlight slightly different elements of this policy problem, several features are typically given prominence (Rosenbloom et al., 2019). The first relates to the temporal scope of the climate challenge. Climate change is playing out over multiple decades and even centuries as GHGs have been

accumulating since the industrial revolution and the impacts of current emissions will be felt far into the future (IPCC, 2014c). A credible policy response requires that costs be borne in the near-term in order to avoid devastating consequences in the long-run (Stern, 2007). Political systems and even human cognition, however, are not well adapted to long-term considerations and privilege far shorter time horizons (Pahl et al., 2014).

Second, moving away from existing arrangements implies a significant depth of technological but also social change (O'Brien, 2018). Responding to the climate challenge is not simply a matter of seamlessly switching between carbon-intensive technologies and emerging low-carbon innovations. Put simply, addressing this challenge is about transforming the core ways society functions: the way we produce goods, move people and products, build homes and plan cities, and so on. This degree of change means that policy and planning surrounding climate change is confronted with considerable complexity, reflecting multiple and interlinking adjustments in social practices and norms, infrastructures and technologies, markets and business models, as well as rules and regulations (Geels and Schot, 2007; Smith et al., 2005). And so, contemplating and pursuing the potential low-carbon societal arrangements of the future involves engaging with indeterminate combinations of social and technical elements.

Third, given the multi-decadal timescale and degree of change required, there is considerable uncertainty about exactly how this transition will unfold (Hughes et al., 2013) or how decision-makers might best move to realize possible low-carbon futures (Polasky et al., 2011). This is not only about the future of the climate system (e.g., temperature rise and impacts) but also relates to the factors driving emissions growth (e.g., economic growth) and influencing the adoption as

well as outcomes of policy responses (e.g., international climate agreements, economic shocks, the pace and direction of technological development, and environmental impacts). So, while transitions might be deliberate affairs, they are not scripted, deterministic, or linear (Geels, 2010; Geels et al., 2017b). Rather, responses to the climate challenge must continually contend with uncertainties and adapt to evolving circumstances. This also highlights the important place of experimentation and learning-by-doing in moving toward a low-carbon future (Hildén et al., 2017; Hoffmann, 2012; Kivimaa et al., 2017; Rosenbloom et al., 2018b; Sengers et al., 2016).

Fourth, climate change is marked by important political and distributional tensions. The burden of climate action, costs of the low-carbon transition, and impacts of climate disruption are not evenly distributed across time, geographic regions, economic sectors, or socio-economic strata (Mendelsohn et al., 2006; Tol et al., 2004). And, in light of the uncertainties and complexities that mark this policy problem, there are multiple competing visions for change that are tied to diverse interests (Curran, 2012; Eames et al., 2006; Lilliestam and Hanger, 2016). Even while the scientific basis of climate change may be clear (IPCC, 2013), the low-carbon transition and the direction it should take are politically contested given that alternative courses of action present vastly different implications for the distribution of costs and benefits across temporal, geographic, social, and economic domains (Meadowcroft, 2011). Consider, for instance, how a low-carbon transition that places emphasis on small-scale and distributed renewables might impact the nuclear energy industry, economies that rely heavily on this industry to generate wealth, and even individuals with livelihoods tied to this source of power. Political contests over the direction of low-carbon change not only link to potential innovation trajectories (the prospects for specific technologies) but also divergences about the guiding principles (equity or

efficiency), types of institutional arrangements (market-based or regulatory approaches), and patterns of ownership (small-scale distributed versus large-scale investor-led) that may best orient low-carbon change. And so, shifting arrays of societal actors seek to influence the orientation of climate policy and planning in ways that align with their perceived interests.

The combination of the above features of the climate challenge – (i) the long timespan associated with this change, (ii) the depth of change required, (iii) the uncertainties and complexities involved, and (iv) deep political tensions – make the pursuit of low-carbon transitions particularly daunting. On the one hand, sustained and ambitious policy efforts are needed to drive fundamental changes across an array of societal sectors (from electricity to agriculture). On the other hand, profound uncertainties about the future course of technological, economic, and social development mean it is not possible to precisely foresee which responses are best able to deliver the low-carbon energy systems of the future. And, with this, there are multiple and contested visions for change and courses of action that have different distributions of costs and benefits for the interests involved.

2.3 The increasing use of pathways to contemplate the low-carbon transition

It is within this context that the concept of "pathways" has increasingly been drawn upon to engage with the low-carbon transition. Diverse constituencies have used this concept to frame the challenge of pursuing decarbonization, referring variously to the responses and actions (e.g., carbon pricing systems), technological and social innovations (e.g., electric vehicle diffusion), as well as broader patterns of change in natural and human systems associated with a shift toward desirable low-carbon arrangements. Climate policy frameworks have begun to use this concept

to encompass post-carbon societal development strategies (Wiseman et al., 2013). The concept of pathways is also playing an important role within a series of analytical approaches that explore the processes connecting current system configurations to alternative low-carbon system states and seek to inform climate planning (Geels et al., 2016a; Turnheim et al., 2015).

With respect to these analytical approaches, there is growing interest in using the concept of pathways to capture the complexity and uncertainty of low-carbon transitions (see Figure 1). According to Swart et al. (2004, p. 137), a core task of these approaches is "to examine the range of plausible future pathways of combined social and environmental systems under conditions of uncertainty, surprise, human choice and complexity". Modelling research, for instance, has considered long-term trajectories of GHG emissions (e.g., Moss et al., 2010; Nakićenović, 2000; van Vuuren et al., 2012, 2011) in order to inform climate impact assessments under different long-run atmospheric concentration and temperature levels (e.g., Hasegawa et al., 2014; Hayhoe et al., 2004; Xiong et al., 2007). Another strand of work has explored market and technological dynamics underlying movement toward potential low-carbon futures (e.g., Bataille et al., 2016; Jacobson et al., 2015; Jacobson and Delucchi, 2009; Morrison et al., 2015), assessing alternative mitigation options, relative abatement costs, and whether these options might be robust across multiple possible futures. Still others have examined interacting social and technical patterns of change within societal systems as they are reconfigured in a more sustainable fashion (e.g., Geels and Schot, 2007; Smith et al., 2005), shedding light on the general patterns that define transition episodes (e.g., Papachristos et al., 2013) along with potential strategies for unlocking processes of transformative change (Loorbach and Rotmans, 2010).

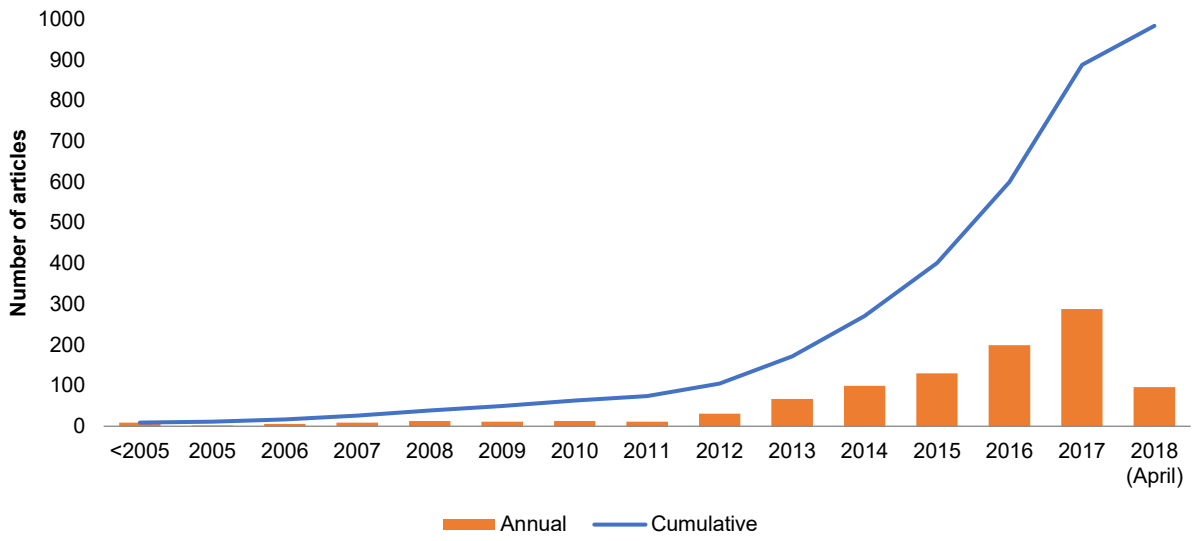


Figure 1: Scholarly works on "pathways" in the context of low-carbon transitions

This figure illustrates how the concept of pathways has been increasingly called upon within the literature engaging with low-carbon transitions. Results are based on a keyword search[1] of the Scopus database of peer-reviewed academic research. After eliminating false positives and duplicates, 984 articles were captured.

The concept of pathways has also gained prominence in political debate around climate-energy policy. At the international level, political leaders have recast development priorities in terms of pathways to low-carbon economies (G7, 2015; G8, 2008). The United Nations Secretary-General Ban Ki-moon, for instance, commended China's mounting response to climate change by

1 In line with Rosenbloom (2017), the following keyword string was used to query the Scopus database: (TITLE-ABS-KEY("low-carbon pathway*" OR "decarbonisation pathway*" OR "concentration pathway*" OR "emission* pathway*" OR "transition pathway*")) AND DOCTYPE(ar) AND SUBJAREA(MULT OR ENER OR ENVI OR ARTS OR BUSI OR ECON OR SOCI) AND LANGUAGE(english).

signalling that a “low carbon climate resilience development pathway is achievable” (UN News, 2016a). Highlighting the interconnected nature of near-term interventions and long-term movement toward more desirable futures, the former president of the UN General Assembly similarly stated that “action now can create pathways out of our current crises and begin the transformation that our world desperately needs” (UN News, 2016b). At the national level, the United Kingdom’s Energy and Clean Growth Minister, for example, cited the need to “march now on a decarbonisation pathway right across the economy and right across the Government” (Mace, 2017).

Aside from this high-level political rhetoric, the concept of pathways has come to form a part of low-carbon transition strategies and climate responses (Wiseman et al., 2013). Take, for example, the European Commission’s “Roadmap for moving to a competitive low carbon economy in 2050” (2011). This early effort sets out plausible low-carbon pathways for key sectors based on modelling and scenario analyses, identifying cost-effective solutions and averting potential carbon lock-ins. The United Kingdom has also drawn heavily on pathways as part of its “2050 pathways” (2013) and the more recent “Clean growth strategy” (2017). The former is a simulation, visualization, and communication tool that allows users to explore different possible emissions reduction pathways to 2050 based on choices about energy technology alternatives. This reflects the multitude of directions low-carbon change could take as well as the important role of choices about energy sources. With respect to the latter, the strategy examines a range of pathways to a low-carbon economy informed by modelling exercises and marginal abatement cost-curves for different innovations. Not only does it seek to address climate change commitments (e.g., aligning with the UK carbon budgeting process) but also

brings together industrial development and other societal priorities. From this, a sectoral breakdown of promising innovation and business opportunities is outlined (e.g., growing low-carbon energy sources in the power sector and supporting innovation around zero-emission vehicles in the UK automotive industry) along with phased government actions to unlock these possibilities (e.g., renewable energy incentives and R&D spending on vehicle innovation). Other prominent policy frameworks are also taking up pathways to encompass long-term climate action (Environment and Climate Change Canada, 2016; Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, 2016; Ministère de la Transition écologique et solidaire, 2017; The Generation Energy Council, 2018).

Key actors and organizations involved in shaping the decision-making process have also actively used pathways as an analytical approach and problem frame. Most notably, the Intergovernmental Panel on Climate Change (2014b) has widely used pathways in their modelling work exploring emission trajectories – referred to as "representative concentration pathways" – under a range of conditions. The International Energy Agency (2017) has also taken up pathways to investigate energy sector development in the context of climate change. Moreover, the Deep Decarbonization Pathways Project (2015) has used pathways in their modelling exercises scrutinizing potential abatement options. Part of the goal here is to inform policy by identifying robust innovations and responses across a variety of future circumstances consistent with climate change commitments. The Solutions Project (2016) has, in contrast, developed future pathways for an array of national energy systems based on a preferred configuration of wind, water, and solar power. Many other notable initiatives have used pathways as an analytical device to envision or assess potential solutions to the decarbonization

challenge (e.g., Candy et al., 2017; Greenpeace International and European Renewable Energy Council, 2007; McKinsey & Company, 2009; World Economic Forum, 2018). Broader societal actors are also adopting pathways approaches as part of climate change engagement, including for example actors in the oil and gas industry who are exploring a range of pathways defined by alternative global trends, climate policies, and energy mixes (BP, 2017; Shell, 2018).

From this, decarbonization pathways (broadly conceived) appear to be situated at the intersection of *courses of societal development* and *courses of action*. Put simply, pathways bridge past, present, and future to contemplate the intentional pursuit of low-carbon transitions – considering innovative possibilities and responses to reorient society toward decarbonization. And, in this fashion, they are entwined with critical questions such as: where we are (as a jurisdiction, society, or even planet) and where we are going, what is and what could be, which possible future should be pursued and how best might it be reached? Policy and politics play a central role in responding to these questions. Indeed, it is in the realm of policy that low-carbon transitions are being envisioned, assessed, enacted, and contested.

3. Research problem, objectives, and questions

The above discussion suggests that pathways are playing an important role in the governance and analysis of low-carbon transitions. It is also apparent that, to date, there is limited consistency in the use of this concept as a critical problem frame or as part of relevant analytical approaches and policy responses. Indeed, the concept has yet to be explicitly or deeply interrogated. Moreover, while a considerable body of work emphasizes the technological and geophysical dimensions of decarbonization pathways, somewhat less has been done to engage with the

political domains underlying this transformative pursuit (Geels et al., 2017b, 2018; Keary, 2016; Li and Strachan, 2017; O'Brien, 2018). So, while pathways are increasingly becoming entwined with the pursuit of low-carbon transitions, more can still be done to deepen our understanding of the concept and further capture the multiple dimensions entailed by low-carbon change.

In response, this dissertation: (1) scrutinizes how the concept of "pathways" is understood within climate-energy policy and analysis; and (2) attends to the struggles involved in pursuing potential pathways to carbon-neutral energy systems. Two overarching and interrelated research questions orient this work. First, how are pathways understood in the context of the low-carbon transition? And second, how are the socio-technical responses that help make up these pathways contested and shaped through politics?

4. Theoretical perspectives: transitions studies and complementary discursive perspectives

In order to explore the abovementioned research questions, this thesis draws upon theoretical insights from transitions studies and seeks to enrich this body of work with discursive perspectives. Transition studies form the theoretical backbone of this dissertation, with discursive approaches providing complementary insights and tools to more deeply engage with the politics of transitions. This section begins by discussing transition studies, outlining foundational concepts, prominent perspectives, and key debates surrounding this research tradition. The discussion then moves to consider the way in which discursive perspectives could enrich transition studies. This union of approaches helps to highlight and further interrogate four interacting political domains of low-carbon transitions: ideas, institutions, interests, as well as innovations and infrastructures.

4.1 Transition studies

Over the past two decades, transition research has emerged as an increasingly important interdisciplinary field of study focused on analyzing processes of system change to address sustainability challenges such as climate change (Markard et al., 2012). Informed by diverse theoretical perspectives from evolutionary economics (e.g., Nelson, 1994; Nelson and Winter, 1982, 1977), innovation (e.g., Bijker et al., 1987; Dosi, 1982; Hughes, 1987), and complex systems (e.g., Giddens, 1984), transition studies have developed a series of useful insights about the way in which established societal arrangements move from one configuration to another over time in such a fashion as to address pervasive environmental challenges (Grin et al., 2011a). Broadly, transitions can be understood as "transformation processes in which society changes in a fundamental way over a generation or more" (Rotmans et al., 2001, p. 15) or "transformations in the way societal functions such as transportation, communication, housing, feeding, are fulfilled" (Geels, 2002, p. 1257). These episodes of transformative change involve "alterations in the overall configuration of… systems, which entail technology, policy, markets, consumer practices, infrastructure, cultural meaning and scientific knowledge" (Geels, 2011, p. 24). In this way, sustainability transitions "are long-term, multi-dimensional, and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption" (Markard et al., 2012, p. 956). The following discussion will elaborate the foundational concepts underpinning transition studies, briefly outline the core perspectives that have emerged within this field of study, and trace relevant debates surrounding transitions research.

Foundational concepts. The first foundational concept in transition studies relates to *co-evolution* (Geels, 2005b; Grin et al., 2011a; Kemp et al., 2007). In the broadest sense, co-evolution refers to the way in which the development of society and technology are deeply interwoven. As Silva and Stocker (2018, p. 62) note, "society and technology mutually shape each other, instead of one determining the other". In this understanding, patterns of social and material organization are inextricably interlinked and must be examined together in order to meaningfully understand the long-term course of societal development and how transitions to sustainability may unfold (Foxon, 2011). Transition scholars, therefore, speak of transitions as *socio-technical* processes that not only involve changes in technology but also the economic, political, and social features underlying society (Berkhout, 2008).

In a more precise sense, the concept of co-evolution directs attention toward the interconnected social and material configurations that seamlessly interact to meet certain societal functions (e.g., electricity provision or transport) and must undergo change to resolve severe ecological challenges (Geels, 2004). That is, transitions are principally concerned with *socio-technical systems* composed of a variety of tightly interrelated social and material elements that have become deeply engrained within the fabric of society, representing the dominant 'way of doing things'. These systems embrace institutions and rules, norms and practices, politics and power relations, technologies and infrastructures, markets and ownership, as well as many other factors. Consider, for instance, the seamless way in which assemblages of centralized fossil fuel-based power plants, transmission and distribution lines, along with electric power markets function together in providing electricity services.

A second conceptual underpinning of transition studies concerns the processes of *continuity* underlying and helping to stabilize dominant and unsustainable socio-technical system configurations. Processes such as lock-in (Unruh, 2000) and path-dependency (Berkhout, 2002) form central tenets of transition studies, explaining the predominance of incremental trajectories of innovation and how carbon-intensive courses of societal development persist in the face of more sustainable alternatives. As transition studies draw from an extensive body of perspectives on continuity (Arthur et al., 1987; Dosi, 1982; Mahoney, 2000; North, 1990; Pierson, 2000; Unruh, 2000), here I provide only a relatively broad overview of the key ideas commonly used to explain the reproduction of established (and often unsustainable) socio-technical systems (Foxon, 2002; Klitkou et al., 2015).

Transition studies recognize that certain socio-technical system configurations tend to persist over long periods of time – they gather momentum, become deeply entrenched, and are increasingly difficult to dislodge as time passes (Klitkou et al., 2015). According to Unruh (2000), the stability promoting mechanisms underlying a socio-technical system configuration can be usefully summarized in terms of: (1) the vast sunk costs associated with current technological and institutional arrangements, (2) the accumulation of experience around established technologies and institutions, (3) self-fulfilling expectations about the persistence of these arrangements, and (4) increasing benefits of moving in the established direction – e.g., standardization and access to financing. Beyond these four mechanisms, others note that specific institutional and technological arrangements tend to become accepted as natural the longer they are in place, possible alternative institutional and technological trajectories are not equally viable at any point in time, and there are often mutually reinforcing dynamics between a given

institutional or technological setup and its beneficiaries – i.e., vested interests (Roberts et al., 2018; Rosenbloom et al., 2019; Schmidt and Sewerin, 2017). In this view, existing system configurations tend to be reproduced by a variety of interlinked social and material forces that are both structural as well as agential in nature – enmeshed, interacting, and often mutually supporting sets of rules, technologies, infrastructures, practices, ownership structures, actor networks, and many other factors (Geels et al., 2016b).

A third conceptual element revolves around *systems level change* (Geels, 2005c). As mentioned, transitions concern the way in which societal functions are fulfilled and relate to changes in socio-technical systems such as transport, agriculture, and electricity. Studying transitions, therefore, involves scrutinizing change at the level of systems as opposed to more limited adjustments in specific technologies, products, or supply chains. Given the deeply embedded nature and enmeshed supporting features of carbon-intensive socio-technical systems, transition studies tend to be predicated on the notion that moving toward sustainability entails a radical shift in the configuration of socio-technical elements making up these systems (Martínez Arranz, 2017). Consider, for instance, movement away from centralized infrastructure and large power producers in the electricity system toward distributed electricity sources, local ownership, and consumer participation (Lilliestam and Hanger, 2016). This degree of complex and pervasive change stands in contrast to more incremental adjustments, which may lead to correspondingly smaller environmental improvements (e.g., end of pipe solutions).

A fourth foundational concept within transition studies concerns *temporality*. Transitions are understood as taking place over multiple decades and involving an accumulation of change over

time. While proximate developments may punctuate the course of societal development and particular directions of socio-technical change, transition processes are regarded as involving multiple phases and sequences of change that span decades (Grin et al., 2011a). Drawing on the innovation diffusion curve (Rogers, 1983), Rotman et al. (2001) suggest that transitions occur over four phases: (1) predevelopment, (2) take-off, (3) acceleration, and (4) stabilization. Asquith (2017) and Geels et al., (2017b) follow a similar line of thinking and propose a slightly varied processual model, suggesting that transitions unfold as radical innovations: (1) emerge at the fringes of the existing socio-technical system; (2) gain momentum as they establish small footholds in market niches; (3) challenge the dominant system configuration as they break through; and (4) realize deep changes within the socio-technical system as widespread adoption occurs. Still others (Rosenbloom and Meadowcroft, 2014) propose that system configurations: (1) may become destabilized as problems are revealed and pressures mount; (2) enter a period of flux as an inflection point is reached based on intensifying pressures; (3) encounter rising contests as challengers and incumbents vie to promote alternative models for reconfiguring the system; and (4) eventually crystallize around a new model. More granular stages have also been introduced that elaborate particular transition phases such as destabilization (Turnheim and Geels, 2012). Importantly, transitions do not necessarily follow a set sequence of phases and may combine certain elements or even regress in some cases (Grin et al., 2011a). From this, debates have emerged about where we are located in these sequences, where we are headed, and how fast we might get there (Markard, 2018; Sovacool, 2016; Sovacool and Geels, 2016).

Temporality, however, not only relates to general phases but also the specific dynamics that shape transitions. Indeed, transitions are defined by sequences of choices and system interactions

along with the sedimentation of outcomes (Foxon et al., 2013; Rosenbloom et al., 2018a). And so, different directions of change may unfold based on the timing and nature of these system interactions (Geels and Schot, 2007).

Prominent transition perspectives. The above foundational concepts are shared among a number of useful transition perspectives that have gained prominence over the past two decades. According to Markard et al. (2012), the primary transition approaches include the multi-level perspective (Geels, 2011, p. 201, 2002; Geels and Schot, 2007; Smith et al., 2010), transition management (Kemp et al., 2007; Loorbach and Rotmans, 2010; Rotmans et al., 2001), strategic niche management (Kemp et al., 1998; Schot and Geels, 2008; Smith, 2007), and innovation systems (Bergek et al., 2008; Hekkert et al., 2007; Hekkert and Negro, 2009). While each of these frameworks may emphasize slightly different aspects of sustainability transitions, they are largely complementary.

The *multi-level perspective* represents a central theoretical framework in transitions research. According to this perspective, transitions can be conceptualized in terms of interactions among multiple dimensions: niches, regimes, and the landscape (Geels, 2002; Geels and Schot, 2007). Niches are composed of emerging socio-technical innovations such as new low-carbon practices and technologies, supported by evolving networks of actors, that challenge dominant and unsustainable arrangements. They are often considered to be a locus of systems level discontinuity. Regimes embrace the dominant configuration of socio-technical components – rules, institutions, and actor networks but also interrelated infrastructures, material assets, and technological artefacts – that work in concert to meet a particular societal function. These

configurations display path-dependent features (e.g., sunk costs) that constrain choices in such a way as to reproduce existing innovation trajectories and carbon-intensive arrangements (Berkhout, 2002b; Unruh, 2000). The landscape encompasses broader developments and trends (e.g., acute market shocks and changing political administrations but also more gradual 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. What this model emphasizes is that there is "no simple 'cause' or driver in transitions" and that "system innovations come about through the interplay between processes at different levels and in different phases" (Geels and Kemp, 2007, pp. 443–444).

Strategic niche management focuses on the formation of niches as a way to promote shifts from current regimes to more sustainable configurations in the future (Kemp et al., 1998). Niches are regarded as a central driver of radical (in contrast to incremental) change (Raven, 2005), acting as the primary seeds of system transformation and source of path-breaking innovation (Sengers et al., 2016). These spaces offer protection from the harsh competitive pressures of the selection environment embodied by the dominant system configuration (Smith and Raven, 2012). By shielding emerging innovations from competitive pressures, they afford innovators an opportunity to foster the development of novel technologies and practices until they begin to crystallize around new models for meeting a societal function capable of challenging the incumbent configuration. Niches nurture innovations through a variety of processes, including learning-by-doing and networking (Schot and Geels, 2008). The deliberate creation and support of niches through policy intervention (e.g., modifying institutional and infrastructural

commitments) is, therefore, given particular prominence (Kemp et al., 2001). Consider, for instance, how incentive programs for net-zero energy buildings (Brown and Vergragt, 2008) or alternative forms of mobility (Ceschin, 2014) can create opportunities for experimentation. The aim of these interventions (e.g., favorable financing arrangements) is to encourage protective and nurturing processes, while progressively removing support in order to allow innovative socio-technical models to scale up and become increasingly embedded at the regime level (Sengers et al., 2016).

Transition management draws together transition ideas and governance approaches to develop a "practice-oriented model for influencing ongoing transitions into more sustainable directions" (Markard et al., 2012, p. 958). This somewhat more applied approach seeks to develop a management strategy that offers guidance to decision-makers and societal actors interested in realizing transitions in complex systems (Rotmans et al., 2001). It is principally concerned with deliberately guiding transitions along desirable trajectories (Meadowcroft, 2009). Acknowledging that the full control of transitions is not possible, the aim here is rather to "manage these problems in terms of adjusting, adapting and influencing by organizing a joint searching and learning process, focused on long-term sustainable solutions" (Grin et al., 2011b, p. 140). From a considerable body of action-oriented research and experience surrounding sustainability initiatives, an approach has taken shape that advocates bringing together innovators (pioneers and niche players) in a process of visioning, co-learning, and monitoring. The general approach unfolds as follows: "(i) structure the problem in question and establish and organize the transition arena; (ii) develop a transition agenda, images of sustainability and derive the necessary transition paths; (iii) establish and carry out transition experiments and mobilize the

resulting transition networks; (iv) monitor, evaluate and learn lessons from the transition experiments and, based on these, make adjustments in the vision, agenda and coalitions" (Loorbach and Rotmans, 2010, p. 238). In the same vein as strategic niche management, this practice-oriented process creates space for agents of change to develop alternatives that may begin to challenge unsustainable regimes (Rotmans and Loorbach, 2009).

The *innovation systems* perspective focuses on the development of innovations and the institutional systems in which they are embedded. This highlights both the "emergence of novel technologies *and* the institutional and organizational changes that have to go hand in hand with technology development" (emphasis added; Markard et al., 2012, p. 959). Building on the concept of national innovation systems (Dosi et al., 1988; Freeman, 1987; Lundvall, 1992), this perspective attends to the ecosystem of institutional features that enable processes of innovation and encourage economic growth. A prominent strand of this research aims to elaborate the critical functions that institutions must carry out in order to support the development and diffusion of emerging technologies that hold promise in addressing ecological concerns (Hekkert et al., 2007; Hekkert and Negro, 2009). These functions include: (1) entrepreneurial activities (the presence of entrepreneurs who leverage new technologies, knowledge, networks, and markets to create business opportunities); (2) knowledge development (learning mechanisms such as learning-by-doing); (3) knowledge diffusion through networks (diverse actor networks engaged in the active exchange of information to inform actions); (4) guidance of the search (activities that help guide the direction of change and shape expectations such as deployment targets); (5) market formation (the creation of niches within which more sustainable innovations can develop); (6) resource mobilization (human and financial capital inputs); and, (7) creation of

legitimacy (advocacy coalitions helping to catalyze change and defend against resistance from incumbents). The specific institutional structures and functions that act as barriers to radical innovation are a central concern of this work (Negro et al., 2012, 2007), which has been used to identify sites where policymakers might intervene to unlock more transformative trajectories of change (Wieczorek and Hekkert, 2012). In this way, there is a growing interest in considering the environmental outcomes associated with particular systems of innovation and their role in supporting or limiting the adoption of change processes toward sustainability (Markard et al., 2012).

Relevant debates. While transition studies have received much interest and show particular promise in analyzing sustainability challenges such as climate change, they have also been subject to a number of criticisms (e.g., Genus and Coles, 2008; Markard and Truffer, 2008; Shove and Walker, 2007; Smith et al., 2010, 2005). As these criticisms are far ranging (from attending to the geography of transitions to the operationalization of key concepts) and have prompted a number of enhancements (Coenen et al., 2012; Geels, 2011; Geels et al., 2016b; Markard et al., 2015), this discussion will focus on two strands of debate that are particularly relevant for this thesis. These debates revolve around a potential bias toward niche-driven change processes (Berkhout et al., 2004; Markusson et al., 2012) as well as attending more closely to the role of politics and agency within transitions (Meadowcroft, 2011, 2009; Shove and Walker, 2007; Smith et al., 2010).

With respect to the first debate, early transitions studies tended to foreground niche-level processes (e.g., the role of challengers and the accumulation of market share for novel

innovations) as critical factors in driving systems change (Geels, 2002; Kemp et al., 2001, 1998). Responding to this "bottom-up *niche bias"* (Geels, 2011, p. 32), a considerable body of research has emerged which explores "whether there may be a greater plurality of possible transformation pathways" (Berkhout et al., 2004, p. 48). This work accounts for more differentiated sites of change and complex patterns of interaction (Geels et al., 2016b; Geels and Schot, 2007; Smith et al., 2005). Based on historical observations (e.g., Geels, 2005a), multiple patterns of system change (i.e. "transition pathways") have been identified which offer lessons for unfolding sustainability transitions. A range of studies have leveraged these lessons to grapple with movement toward sustainability, examining in greater detail what this type of change might look like and how it might be facilitated (e.g. Foxon, 2013; Geels et al., 2016a; Turnheim et al., 2015). From this, transitions studies have shown that transition pathways: are not comprised of one dominant pattern (e.g., niche-driven change) but rather involve a plurality of possibilities and cascading interactions that can manifest in vastly different directions of change (Geels and Schot, 2007; Smith et al., 2005); are deeply temporal as they involve sequences of choices (around institutional and technological arrangements, in particular) and consequences over many rounds of action that branch in different directions (Foxon et al., 2013; Rosenbloom et al., 2018a); and, embody processes of both continuity and discontinuity – they exhibit path dependent features but also allow for path creation opportunities (Geels et al., 2016b). Pathways, in this view, concern "decision making at critical points" (Foxon et al., 2013, p. 156) and "event-chains and rounds of moves and counter-moves" (Geels et al., 2016b, p. 898), particularly with respect to key sites of contestation (e.g., institutional and infrastructural commitments around climate and energy).

The second key debate engages more deeply with these sites of contestation by elaborating the politics of transitions. Over the past decade, transition perspectives have been criticized for not always attending closely enough to the politics of shifting societal systems toward sustainability. Some have, for example, raised questions about how transition management confronts the issues of power, normativity, and conflict (Meadowcroft, 2009, 2007; Shove and Walker, 2007). Still others have suggested that the multi-level perspective emphasizes structural factors and allows less space for agency (Genus and Coles, 2008; Smith et al., 2005). This has led to calls (from Meadowcroft, 2011, among others) for the development of more politically-sensitive transition approaches that attend more carefully to the interactions among core political domains: *interests* (strategies and positions of political actors), *institutions* (layered norms, practices, and relations of power), and *ideas* (frames of reference that shape problem definitions and solution spaces). In response, politics and agency have emerged as central concerns in transition studies (Köhler et al., 2019).

Of the growing body of work that has taken shape as part of this 'political turn', two strands are particularly prominent. The first engages more deeply with agency, elaborating the way in which actors interact and strategically seek to influence transition processes (Berggren et al., 2015; Geels, 2014; Hess, 2016; Ingram et al., 2015; Smink et al., 2015). The second explores complementarities among transition perspectives and political science approaches to develop more politically-informed transition studies (Cherp et al., 2018; Kern and Rogge, 2018; Roberts et al., 2018; Rosenbloom et al., 2019).

With respect to the first strand, a growing body of research has emerged that elucidates the strategic positioning of actors around alternative transition pathways. Recent work has, for instance, elaborated the considerable resistive capabilities of actors aligned with the regime, indicating that incumbent actors often form close alliances with decision-makers to perpetuate carbon lock-in (Geels, 2014) and that these actors may limit or channel the diffusion of low-carbon innovations in ways that are amenable to their interests (Smink et al., 2015). Others make comparable observations but call attention to the varied strategies employed by incumbent actors as they are active at both regime and niche levels (Berggren et al., 2015; Ingram et al., 2015). Importantly, Fuenfschilling and Truffer (2014) suggest that there can be tensions between the different actors and institutional logics surrounding the regime. This not only reinforces the notion that actor orientations are semi-coherent (actor positions can be dynamic and conflicting) but also points to potential cleavages and nascent pressures building within fossil fuel-based systems that could be strategically opened up.

In relation to the constellations of actors surrounding the niche, transition studies have pointed to the varied positions these actors adopt in relation to protective spaces for low-carbon innovations (Raven et al., 2016; Smith and Raven, 2012). They show that, despite holding a general alignment with particular clean energy niches, actor networks can adopt different orientations in regard to policy support, innovation trajectories, as well as uptake and market integration. Still others shed the "niche-regime dichotomy" to reflect the complex and dialectical relationship between contending interests in driving change processes, locating the politics of transitions within broader multi-actor interactions (Avelino et al., 2016, p. 558). Together, this points to the

diverse strategies employed by contending actors as they leverage their resources (ideational, material, and so on) to open, block, or influence change processes.

In regard to the second strand, new research agendas have emerged which seek to unlock complementarities among transition and political science perspectives (Cherp et al., 2018; Roberts et al., 2018). Scholars have drawn on historical institutionalism (Lockwood et al., 2017), discursive institutionalism (Kern, 2012), and policy process theories (Kern and Rogge, 2018), among many other approaches, to enhance the political sensitivity of transition studies. As part of this, Geels (2010) and others (Kern and Rogge, 2018) have argued that discursive approaches can usefully complement transition perspectives, with a number of transition-discourse crossovers demonstrating the fruitfulness of this integration. Geels and Verhees (2011), for instance, develop a cultural performative approach to explicate the way in which actors build and maintain legitimacy around technologies and their associated development trajectories. Smith et al. (2014) draw on discourse to explore how advocates of emerging innovations undertake narrative work to build legitimacy for alternative transition pathways by linking the socio-technical features of technologies to the context in which they diffuse. Bosman et al. (2014), on the other hand, adopt discursive techniques to refine the regime concept through an investigation of the language used by incumbent actors in relation to energy development, identifying the fragmentation of storylines used by incumbents and pointing to emerging conditions for regime destabilization. Similarly, Rosenbloom et al. (2016) employ a discursive approach to examine the active and creative use of storylines in struggles over the legitimacy of low-carbon innovations. Building on these efforts, more recent work examines the framing contests surrounding the diffusion of emerging innovations (Ganowski et al., 2018; Mallett et al., 2018),

the coherence of dominant discourses (Leipprand and Flachsland, 2018; Roberts, 2017), and the positioning of actors within discursive struggles around innovations (Falcone et al., 2018).

4.2 Enriching transition studies with complementary discursive perspectives

As the above discussion indicates, discursive approaches are playing an increasingly important role in transition studies. With this, transition research has made considerable progress in foregrounding political dynamics and addressing earlier criticisms concerning politics and agency. Yet, more can still be done to attend to the politics of transitions by drawing on discursive traditions.

Within the wider literature on environmental policy and politics, discourse has attracted considerable and sustained interest as "it appreciates the messy and complex interactions that make up the environmental policy process" (Hajer and Versteeg, 2005, p. 176). A number of particularly prominent contributions have emerged in this area, including, for example, Hajer's (1993) seminal analysis of actor coalitions involved in (re)producing particular narratives around acid rain, along with the work of Dryzek (2012) and Hajer (1995) on broader environmental discourses and actor dynamics. Others have used discursive approaches to explore critical frames with implications for the environment such as 'transitions' (Smith and Kern, 2009) and 'the sharing economy' (Martin, 2016). Beyond this, studies have drawn upon discourse to explore the politics surrounding specific policy instruments (e.g., Ascui and Lovell, 2011) and innovations (e.g., Cotton et al., 2014). In this fashion, discursive perspectives have helped inspire many rich strands of research around environmental challenges (Hajer and Versteeg, 2005).

In the transition literature, existing studies drawing on discursive perspectives (e.g., Audet, 2016; Mallett et al., 2018; Späth and Rohracher, 2010; Stephens et al., 2008; Teschner and Paavola, 2013) link to an array of traditions, spanning from linguistics (Lakoff and Johnson, 1980) to communications (Gamson et al., 1992; Gamson and Modigliani, 1989) to anthropology (Mühlhäusler and Peace, 2006) to political and policy studies (Dryzek, 1990; Fischer and Forester, 1993; Hajer, 1995b; Schmidt, 2010, 2008). Given that this thesis concentrates on the policy and political dimensions of low-carbon transitions, the latter tradition is given particular emphasis. Broadly, this tradition recognizes the complexity of critical societal challenges and rejects more traditional explanations of policy and planning (Fischer and Forester, 1993). It is predicated on the notion that policymaking and policy analysis (around climate change, for example) are socially constructed, political processes that are shaped by competing interpretations, value judgements, and interests (Hajer, 1993).

According to this research tradition, a particularly promising way to examine policy processes is by attending to the expression of ideas through language – discourse. In this view, *discourse* can be defined as "an ensemble of ideas, concepts and categories through which meaning is given to social and physical phenomena" (Hajer and Versteeg, 2005, p. 176). It provides a "framework for making sense of situations, embodying judgments, assumptions, capabilities, dispositions, and intentions" (Dryzek, 2006, p. 1). At base, discourse forms the basis for thinking about and acting in a complex world (Fischer and Forester, 1993).

Perhaps most importantly, however, discourse is not simply a politically neutral repertoire for meaning-making (Stone, 2001). Rather, the use of ideas, concepts, and categories is a creative

and strategic process that embodies the "basic terms for analysis, debates, agreements, and disagreements" (Dryzek, 2006, p. 1). Indeed, because the physical world is complex and multiple interpretations coexist simultaneously, actors creatively and strategically leverage ideas, concepts, and categories to help construct social and physical realities in ways that advantage particular responses (e.g., technologies and policies) and interests (Hajer, 1995; Schön, 1993; Stone, 2001). Actors play a critical role here as they struggle over meaning in ways that seek to modulate the envelope of possibilities around policy problems, convince the public and decision-makers of the (in)appropriateness of certain courses of action, and align policymaking outcomes with their perceived interests (Hajer and Versteeg, 2005).

Taken together, this discussion points to the significant role of ideas in environmental politics and policy, in general, and low-carbon transitions, specifically. It also suggests that attending to discourse is a particularly promising way to capture the contests over ideas, concepts, and categories that help shape policy responses to climate change. That is, discursive approaches reveal how actors actively vie to influence the definition of climate-energy policy problems and privilege certain responses through a process of meaning-making. Moreover, scrutinizing the creative and strategic use of ideas can help capture how key concepts are used to frame ecological challenges, evolve over time, and are subject to continuous contestation and reinterpretation (Meadowcroft and Fiorino, 2017).

This thesis seeks to enrich transition studies with discursive perspectives in order to further elucidate the political dynamics underlying transitions toward decarbonization. Drawing these perspectives together, a specific aim is to more explicitly reflect the role of the interacting

political domains mentioned earlier (ideas, interests, and institutions) in shaping low-carbon transitions. Yet, not only can attending to discourse gain further traction on these interacting political domains, it can also shed light on the way these domains impact and are themselves impacted by the material systems that are viewed as essential to low-carbon transitions: innovations and infrastructures (Foxon et al., 2013; Rosenbloom et al., 2018a; Schmidt and Sewerin, 2017). In this way, discursive perspectives show particular promise in revealing how actors actively use *ideas* to influence policy responses (commitments about *institutions* as well as *innovations* and *infrastructures*, in particular) in such a way as to reinforce their perceived *interests* (see Figure 2). Consider, for instance, how narratives about climate-energy problems (e.g., painting fossil fuel power sources as integral to electricity system reliability) may point to particular responses (e.g., institutional and infrastructural commitments around carbon capture and sequestration) that advantage certain interests (e.g., those aligned with fossil fuels) over others (e.g., distributed renewable energy power producers). Interrogating the use of language within climate-energy policy and planning may, therefore, help further elaborate the role of agency and politics in transitions, uncovering how actors strategically use ideas to influence the direction of system change.

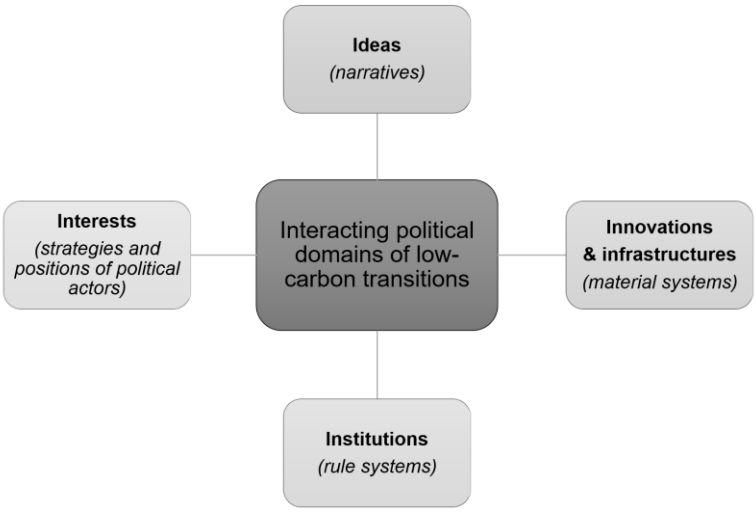


Figure 2: Interacting political domains of low-carbon transitions

This figure is adapted from Rosenbloom (2018)

5. Research approach and overview of the three studies

This section discusses the research approach and the three studies making up the core of this thesis. It begins by discussing some overarching choices related to research strategy. Subsequently, it provides a rationale for the three studies that constitute the thesis as well as the context in which two of these studies are embedded. Finally, an overview of the three studies is provided along with a discussion of the specific methodological tools deployed in each instance.

5.1 Overarching research strategy

The overarching research strategy adopted by this thesis is exploratory and interpretive. This orientation not only aligns with transition studies (Geels, 2010; Geels et al., 2016a; Turnheim et al., 2015) and discursive perspectives (Fischer, 2003; Hajer, 1995) but also the phenomenon under study. Geels (2011, p. 34), for instance, notes that the "appropriate application [of

transition perspectives] requires both substantive knowledge of the empirical domain and theoretical sensitivity (and interpretive creativity) that help the analyst 'see' interesting patterns and mechanisms". Similarly, Fischer (2003, p. 140) argues for the "fundamental role of interpretive analysis in rendering the meaningful categories employed in understanding real life problems" – here, the climate challenge and what might constitute an appropriate response. Moreover, an exploratory posture aligns with the emergent and complex political properties of unfolding low-carbon pathways. As it is not yet possible to determine whether particular experiences will result in a low-carbon future, there is an important role for exploratory work that examines specific experiences that have the potential to do so and generates useful lessons for confronting this challenge.

The three studies making up this thesis deploy varied research strategies and analytical approaches. Common to all, however, is the qualitative analysis of written sources, which is a staple of the explorative and interpretive traditions described above. Over 1000 documents were analyzed as part of this research program, including scholarly works, newspaper articles, government reports, and submissions to stakeholder consultations. The analysis principally revolved around the use of ideas in expert and popular discourse around climate-energy policy and planning, identifying emergent categories, actor positions, and the structure of arguments. Qualitative analyses were complemented by the use of descriptive statistics (e.g., frequency counts of certain actor positions or arguments), the analysis of energy data (e.g., electricity output or installed capacity), the analysis of imagery (e.g., different representations of pathways), and the development of diagrammatic illustrations (e.g., maps of actor positions or scientific contributions). Findings were continuously revisited in light of engagement with the empirical

data and the comments of thesis committee members, peer-reviewers, and experts at the conferences where this research was presented.

The case study method also plays an important role in this research strategy. This method can be defined as the "intensive study of a single case for the purpose of understanding a larger class of cases" (Gerring, 2011, p. 1138). Transition research draws heavily on case studies as they help capture the contextual richness and complex patterns (e.g., co-evolutionary feedbacks) that mark processes of system innovation (Asquith et al., 2017; Geels, 2011, 2010; Sovacool and Hess, 2017). Case studies are also integral to discursive techniques as they allow researchers to examine, in detail, the interactions around meaning-making and how these patterns are embedded in particular contexts (Fischer, 2003; Hajer, 2006). Perhaps most importantly, case study methods have considerable promise in generating "good examples" that can be used to distill lessons about the phenomenon of interest (Flyvbjerg, 2001). In this fashion, selecting critical or extreme cases may help "reveal more information because they activate more actors and more basic mechanisms in the situation studied" (Flyvbjerg, 2006, p. 78). This case selection approach resonates with the problem-oriented nature of transition scholarship – attention tends to be directed toward cases that hold particular promise for informing the pursuit of low-carbon pathways. This further aligns with the explicitly normative orientation of this program of research, which is inclined toward accelerating the low-carbon transition.

Further discussions of research design are presented in the individual studies.

5.2 Rationale for the three studies making up the thesis

Three articles make up the core of this thesis, each of which responds to one or more of the research questions outlined above (see Section 3) and makes a series of interrelated contributions to the literature (see the Conclusion). The first article is entitled "Pathways: an emerging concept for the theory and governance of low-carbon transitions" and appeared in *Global Environmental Change*. The second article is entitled "Framing low-carbon pathways: a discursive analysis of contending storylines surrounding the phase-out of coal-fired power in Ontario" and is published in *Environmental Innovation and Societal Transitions*. The final piece is entitled "A clash of socio-technical systems: exploring actor interactions around electrification and electricity trade in unfolding low-carbon pathways for Ontario" and is published with *Energy Research & Social Science*.

These three studies were selected not only because they confront different parts of the questions that animate this research program but also because they emphasize different yet interrelated aspects of the political domains of low-carbon transitions identified as part of the theoretical discussion (see Section 4 and Figure 2). While all of the studies underscore the central role of ideas and discursive conflicts in transitions, paper 1 is particularly concerned with interrogating the interpretations and implications of an emerging concept that has come to frame the challenge of moving toward decarbonized futures: that is, the concept of "pathways". Paper 2 highlights the role of ideational conflicts surrounding *historical* steps along a low-carbon pathway: the phase-out coal-fired power in Ontario. By examining these conflicts, this study elucidates how contending interests struggled over specific institutional and infrastructural commitments that would transform the electric power system. Paper 3 focuses on ideational struggles around

potential institutional and infrastructural commitments that might constitute *future* pathways toward decarbonization in Ontario, revealing how actors are beginning to position themselves in relation to policy options. In this fashion, paper 1 lays the groundwork for understanding the concept of pathways in the context of low-carbon transitions. Paper 2 then moves to explore a historical case of steps that have already been taken along a low-carbon pathway. Paper 3, in contrast, looks at a case of emerging steps that could be taken to move further along a low-carbon pathway.

The province of Ontario is an interesting context to study these dynamics for a number of reasons. First, transition studies have tended to focus on European jurisdictions. There are many cases examining unfolding low-carbon transitions in Germany (Leipprand and Flachsland, 2018), the United Kingdom (Foxon, 2013), the Netherlands (Raven, 2007), and other European locations (Bosman and Rotmans, 2016). In contrast, North American jurisdictions have been subject to somewhat less attention in transition studies (some exceptions include Haley, 2015; Hess, 2016; Rosenbloom and Meadowcroft, 2014). Therefore, examining climate-energy engagement in Ontario through a transitions lens represents a promising opportunity to explore less well studied empirical terrain. Second, the coal phase-out in Ontario has been called the "single largest GHG emissions reduction action on the continent", resulting in an annual reduction of roughly 33 Mt of CO2eq (Ontario Ministry of Energy, 2015, p. 3). Not only does this represent a major GHG reduction effort, it is also an instance where a regulatory rather than market-based approach helped promote the journey to decarbonize energy systems. Shedding light on these dynamics is of particular relevance as international jurisdictions (Denmark, Britain, Finland, Germany, and others) embark upon similar initiatives. Lastly, Ontario has

concluded one of the most extensive stakeholder consultations in its history concerning climate-energy planning as part of the 2017 Long-term Energy Plan (Ontario Ministry of Energy, 2016). This consultation captures a diversity of stakeholder voices and represents the first serious attempt in this jurisdiction to simultaneously contemplate the low-carbon future of multiple energy systems (electricity, heat, and transport).

5.3 Overview of the three studies

The first study examines the way in which diverse actors construct meaning around the concept of "pathways" in the context of the low-carbon transition. It engages with the first research question: how are pathways understood in the context of the low-carbon transition? It aims to expose the conceptions, maturation, and implications of this concept in both the practitioner and academic discourse surrounding climate-energy planning. To do this, it carries out a survey of the relevant climate change mitigation literature. A total sample of over 725 written sources was amassed based on a keyword search of the SCOPUS academic database, queries of the online document libraries of prominent actors (e.g., IEA and UNEP), reference tracking efforts (examining the works cited by selected sources), as well as expert opinion (the comments offered during the 2016 International Sustainability Transitions Conference and the peer review process). From this, three core conceptions of pathways are uncovered: biophysical, techno-economic, and socio-technical. These conceptions are constituted by diverse perspectives and approaches, with each emphasizing different yet interconnected dimensions of the decarbonization challenge. This paper also identifies several key attributes and functions of the concept of pathways, including mapping, planning, learning, bridging, and communicating. While this study suggests that the concept of pathways possesses a variety of useful features that recommend its use as a critical

problem frame for low-carbon transitions, it also points to a need for further reflexivity. If the concept is cast too strongly in terms of individual core conceptions, there may be a tendency to emphasize certain dynamics while paying somewhat less attention to others, inadvertently diminishing the complexity of the decarbonization challenge. This has the potential to obscure the sticky social factors and political conflicts inherent to decarbonization while foregrounding particular climate responses such as carbon pricing and technological change. There are also other facets of the concept that have to date received more limited attention, including the political dynamics underlying decarbonization (this thread is picked up in papers 2 and 3). Taken together, this exploration indicates that there is room for the concept of pathways to engage more fully with the range of complexities embodied by low-carbon transitions.

Building on this, the second study explores political dynamics surrounding a historical episode of low-carbon change: the phase-out of coal-fired power in Ontario. In particular, it elaborates the discursive struggles that mark this experience. In this fashion, the paper engages with the second research question: how are the socio-technical responses that help make up low-carbon pathways contested and shaped through politics? Drawing on transition and discourse perspectives, it carries out an analysis of media articles based on a keyword search of the ProQuest Canadian Newsstream database. From this, a total sample of 345 newspaper articles were captured. A mix of thematic and content analysis techniques was used to identify and record the occurrence of prominent storylines. The approach adopted here captures the way in which contending actors frame issues and technologies, modulating possibilities and shaping the sequences of choices that link current societal arrangements to future low-carbon states. The study elaborates how the coal phase-out was defined by the negotiation among competing interests and priorities. It also

suggests that regulatory measures may help to accelerate the pace of transitions and succeed where market approaches are politically untenable. Broadly, results reveal how key political factors interact in constituting pathways to decarbonization.

The third study investigates interactions among energy systems within the context of emerging low-carbon pathways. Drawing upon insights from transition studies and recent debates about 'disruption', this study explores how different energy systems (electricity, transport, and heating) and their affiliated actors are interacting around key pillars of low-carbon pathways: expanded societal electrification and electricity trade. In this way, the paper responds to the second research question: how are the socio-technical responses that help make up low-carbon pathways contested and shaped through politics? In order to elucidate the abovementioned interactions, the study examines actor positions articulated during Ontario's 2017 Long-term Energy Plan consultation that are drawn from three sources. First, formal written submissions to the consultation process. Second, publicly available reports commenting on the LTEP process. And third, commentary in the media in relation to the development of the energy plan. A keyword search of actor websites as well as the Canadian Newsstream database generated a sample of 51 consultation submissions (in the form of policy reports, position papers, or formal letters), 21 publicly available reports commenting on the LTEP process, and 66 newspaper articles. Informed by discursive and transition approaches, these written sources were analyzed to identify key actors and core affiliations. Actor positions were then identified based on coding relevant statements with respect to electrification of transport, electrification of heat, and electricity trade. Steps were taken to crosscheck these positions using additional academic sources. Findings indicate that emerging interactions around electrification of transport are

marked by less conflictual patterns in Ontario, whereas electrification of heat and electricity trade are characterized by deeper frictions. These alignment and tensions could be leveraged by actors seeking to accelerate low-carbon transitions in Ontario.

6. Plan of the thesis

The remaining components of the dissertation proceed as follows. Chapter 2 presents the first study, focusing on the concept of pathways in the context of low-carbon transitions. Following this, Chapter 3 outlines the second study, which investigates political dynamics surrounding the coal-phase out in Ontario. Chapter 4 then moves to the present the third study on energy system interactions in the context of unfolding decarbonization pathways. In Chapter 5, the thesis concludes by taking stock of the contributions of the three studies and reflecting upon future research directions.

Chapter 2 – Pathways: an emerging concept for the theory and governance of low-carbon transitions

Published in Global Environmental Change

Volume 43

March 2017

Pages 37-50

Rosenbloom, D., 2017. Pathways: an emerging concept for the theory and governance of low-carbon transitions. Global Environmental Change 43, 37–50.
https://doi.org/10.1016/j.gloenvcha.2016.12.011

See Appendix 1 for the full text.

1. Abstract

The concept of "pathways" has increasingly come to frame the challenge of transitioning to low-carbon societies. It also shows promise as a bridging concept, encouraging constructive dialogue among the diverse perspectives and constituencies evoking its use. However, its interpretations and attributes are rarely explicit and have yet to be subject to serious scrutiny. This raises important questions for both theory and governance as the way in which a problem is framed shapes how it is understood and addressed, structuring the possibilities considered and privileging certain responses. Therefore, this study explores the concept of pathways in the context of low-carbon transitions, exposing its conceptions, maturation, and implications. Based on a survey of the relevant climate change mitigation literature, this analysis uncovers three core conceptions of pathways in the context of low-carbon transitions: (1) biophysical, (2) techno-economic, and (3) socio-technical. Constituted by diverse perspectives and approaches, each of these three core conceptions emphasize different yet interconnected dimensions of the decarbonization challenge. This analysis also points to several key attributes and functions of the concept of pathways. Yet, while the concept may possess a variety of features that recommend its use as a critical problem frame for low-carbon transitions, it also raises issues that suggest a need for further reflexivity. If the concept is cast too strongly in terms of individual core conceptions, there may be a tendency to emphasize certain dynamics while paying somewhat less attention to others, inadvertently diminishing the complexity of the decarbonization challenge. Beyond this, there are other facets of the concept that have to date received more limited attention, including the implications of choices at critical junctures and the evolving character of social practices. So, there is room for the concept of pathways to engage more fully with the range of complexities embodied by low-carbon transitions.

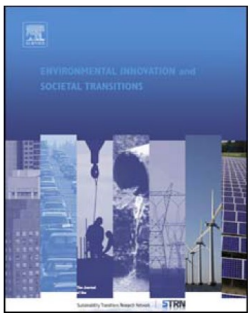
Chapter 3 – Framing low-carbon pathways: a discursive analysis of contending storylines surrounding the phase-out of coal-fired power in Ontario

Published in Environmental Innovation and Societal Transitions

Volume 27

June 2018

Pages 129-145



Rosenbloom, D., 2018. Framing low-carbon pathways: A discursive analysis of contending storylines surrounding the phase-out of coal-fired power in Ontario. Environmental Innovation and Societal Transitions 27, 129–145. https://doi.org/10.1016/j.eist.2017.11.003

See Appendix 2 for the full text.

1. Abstract

Transition studies have made constructive efforts to attend more closely to the politics of sustainability transitions, with discourse emerging as an increasingly important means of interrogating these dynamics. Drawing on discourse perspectives, this study deploys the multi-dimensional discursive approach to explore framing struggles surrounding a climate change mitigation experience of international significance (the phase-out of coal-fired power in Ontario), revealing how ideas, interests, institutions, and infrastructure (the four I's of sustainable energy transitions) interact in constituting pathways to sustainability. This approach captures the way in which contending actors frame issues and technologies, modulating possibilities and shaping the sequences of choices that link current societal arrangements to future low-carbon states. The study elaborates how processes of negotiation among competing interests and priorities helped define the pathway to eliminate coal. It also suggests that regulatory measures may help to accelerate the pace of transitions and succeed where market approaches are politically untenable.

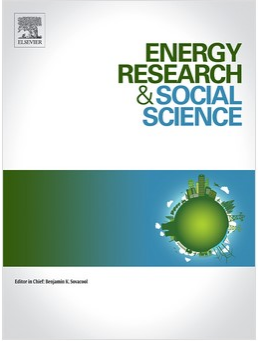
Chapter 4 – A clash of socio-technical systems: exploring actor interactions around electrification and electricity trade in unfolding low-carbon pathways for Ontario

Published in Energy Research & Social Science

Volume 49

March 2019

Pages 219-232



Rosenbloom, D., 2019. A clash of socio-technical systems: exploring actor interactions around electrification and electricity trade in unfolding low-carbon pathways for Ontario. Energy Research & Social Science 49, 219–232. https://doi.org/10.1016/j.erss.2018.10.015

See Appendix 3 for the full text.

1. Abstract

Examining interactions *within* socio-technical systems forms a staple of the literature on sustainability transitions (e.g., interactions among low-carbon challengers and carbon-intensive incumbents in the electricity system). The interactions *between* multiple socio-technical systems have, however, received more limited attention (e.g., how different systems of energy provision might come into contact as part of a low-carbon transition). In response, this study draws upon insights from transition studies and recent debates about 'disruption' to consider how different energy systems (electricity, transport, and heating) and their affiliated actors are interacting around key pillars of low-carbon pathways: expanded societal electrification and electricity trade. These dynamics are explored in the context of Ontario, Canada as this province appears to be moving along a decarbonisation pathway that is anticipated to be widely reflected across transition contexts. Steps along this pathway include the decarbonisation of the electricity system (through the procurement of low-carbon supply from domestic generators and regional interties) followed by the electrification of broader energy end-uses. Based on the analysis of actor positions surrounding climate-energy planning in Ontario, findings indicate that emerging interactions around the electrification of transport are marked by greater alignments, whereas electrification of heat and electricity trade are characterised by deeper tensions. These patterns hold implications for the acceleration of low-carbon transitions.

Chapter 5 – Conclusion

1. Taking stock

This thesis explores the politics of decarbonization pathways, with a particular focus on the responses to and conflicts surrounding the transition to a low-carbon energy future. As part of this, the dissertation: (1) scrutinized how the concept of "pathways" is understood within climate-energy policy and analysis; and (2) further attended to the struggles involved in pursuing potential pathways to carbon-neutral energy systems. Two overarching and interrelated research questions have oriented this work. First, how are pathways understood in the context of the low-carbon transition? And second, how are the socio-technical responses that help make up these pathways contested and shaped through politics? These questions have been addressed through three studies, which have been published in peer-reviewed academic journals and contribute to the literature on low-carbon transitions.

The first study, entitled "Pathways: an emerging concept for the theory and governance of low-carbon transitions", scrutinizes the concept of pathways and reveals that it is playing an increasingly important role in contemplating the deep complexity and uncertainty entailed by a low-carbon transition. Through an extensive survey of the literature on climate change mitigation, this study uncovers different conceptions, attributes, and functions of the concept that recommend its use. However, certain limitations and gaps also exist that may be addressed through further engagement with the multiple dimensions and perspectives surrounding the low-carbon transition.

The second study, entitled “Framing low-carbon pathways: a discursive analysis of contending storylines surrounding the phase-out of coal-fired power in Ontario”, examines the framing struggles marking the decline of coal-fired power in Ontario. Deploying a discursive analysis of media articles around this experience, the paper shows how actors strategically frame energy sources (coal, in this instance) to privilege certain institutional and infrastructural responses. It also indicates that discourse-transition crossovers hold promise in capturing interactions among the political domains that help shape low-carbon energy transitions: ideas, interests, institutions, along with innovations and infrastructures.

The third and final study making up this thesis, entitled “A clash of socio-technical systems: exploring actor interactions around electrification and electricity trade in unfolding low-carbon pathways for Ontario”, investigates emerging patterns of interaction among transport, electricity, and heating systems in the context of the low-carbon transition. Attending to the statements articulated by actors during a prominent energy planning consultation, this study reveals how competing actors are positioning themselves around key pillars of low-carbon pathways: expanded societal electrification and electricity trade. Potential alignments and tensions among interests are identified with implications for climate-energy policy.

In response to the research questions and objectives, this dissertation has interrogated the concept of pathways in the context of the low-carbon transition, examined the role it is playing around the climate challenge, and elaborated political dynamics helping to shape the course of low-carbon development. Broadly, it has argued for further reflexivity and political sensitivity in the use and analysis of pathways. And, adopting a socio-technical conception of pathways, it has

mobilized and extended discursive-transition approaches to elucidate the way in which actors strategically use language to struggle over technology and policy responses in processes of decarbonization.

Taken together, this program of research has generated theoretical advancements within the field of transition studies, made empirical contributions around transitions in the Canadian context, and offered lessons for policy and practice engaged with accelerating low-carbon transitions. While the individual articles making up this thesis offer a range of important insights, here I focus on two core contributions to the literature on low-carbon transitions. The first concerns the way in which diverse constituencies construct meaning around pathways in order to contemplate and act upon the low-carbon transition. The second revolves around elaborating how political contests help shape responses to and processes of decarbonization.

2. A core contribution: understanding the concept of pathways

The concept of pathways is playing an increasingly important role in the governance and theory of low-carbon transitions. On the one hand, the concept has gained prominence as a critical problem frame, taking its place alongside other key environmental concepts such as resilience (Folke, 2006), transitions (Silva and Stocker, 2018), and sustainability (Meadowcroft, 2000). An examination of academic and practitioner discourse surrounding climate change mitigation would suggest that broad constituencies (political officials, leading organizations, scholars, and so on) have adopted the concept of pathways to frame the reorientation of societal development toward long-term decarbonization. On the other hand, the concept has become entwined with analytical approaches and theoretical perspectives grappling with this challenge. Indeed, a range

of research traditions have called upon pathways in order to attend to the different dimensions and processes of change underlying the low-carbon transition.

The first study of this thesis has helped lend structure to these diverse strands of research contributing to the development of the concept of pathways in the context of low-carbon transitions. Three core conceptions of pathways have been distilled: biophysical, techno-economic, and socio-technical. The first understands pathways as *long-term trajectories of GHG emissions linked to particular stabilization targets and derived from macro-level parameters describing human-climate interactions over time*. The second views pathways as *sequences of techno-economic adjustments linking current sector configurations to desirable low-carbon future states*. And the third sees pathways as *unfolding socio-technical patterns of change within societal systems as they move to meet human needs in a low-carbon fashion*. While these conceptions are not mutually exclusive, they emphasize different analytical approaches, theoretical traditions, and dimensions of the challenge.

So, what does this tell us about the promise and pitfalls of pathways for the pursuit of low-carbon transitions? According to the first study of this thesis, pathways show promise in linking present circumstances to long-run decarbonized futures in the context of deep uncertainty and complexity, while mediating among priorities and attending to the consequences of choices. This central role is fulfilled through five functions. First, pathways offer an opportunity to begin to *map* the plurality of low-carbon possibilities open to society based on multiple factors. Second, pathways help *plan* for a low-carbon future by placing near-term decisions in the context of long-term targets, teasing out the consequences of choices and identifying particularly

compelling options. Third, pathways may allow analysts and decision-makers to *learn* about key patterns and processes involved in technological and social change. Fourth, pathways help *communicate* information about possibilities, choices, and tradeoffs that mark alternative directions of low-carbon system change. Finally, findings suggest that the concept of pathways may serve as a *bridge* among the diverse perspectives needed to grapple with the deep complexity and uncertainty of the low-carbon transition. In this fashion, pathways have the potential to capture a plurality of low-carbon possibilities open to society, negotiate and pursue alternative directions of change, and reflect an array of factors that will need to transform in order to reach low-carbon futures.

Yet, while the concept of pathways embraces a range of promising features that recommend its use, there is still room to more strongly represent the social and political character of low-carbon transitions. Despite growing interest in leveraging socio-technical transition perspectives for informing decarbonization efforts (Markard et al., 2012), engagement with pathways has largely emphasized biophysical and techno-economic processes and perspectives. This is occurring in two primary senses: in pathways *analysis* and *governance*. In the former sense, there has not always been sufficient appreciation of the political and social forces that may help shape low-carbon transitions. The first study of this thesis has found that the emphasis is often on formal modelling traditions that have somewhat more difficulty incorporating social and political processes. Others have similarly argued that pathways analysis based predominantly on formal models may not sufficiently engage with the political and social factors that are entwined with transformative low-carbon change (Geels et al., 2017b, 2018; Keary, 2016; Li and Strachan,

2017; O'Brien, 2018). Findings also suggest that there may be dangers if any one perspective or dimension of change is cast too strongly or weakly.

In the latter sense, governance approaches concerned with envisioning and enacting low-carbon pathways have not always been sensitive to the social and political dimensions of the climate challenge. To date, policy and practice has largely focused on the technological and economic components of decarbonization strategies. By extension, this has stressed the adoption of low-carbon technological solutions and the establishment of carbon pricing regimes to gradually reorient markets and drive diffusion over time. Inadvertently, this emphasis may reduce the challenge of decarbonization to one of 'technology switch' and 'setting an appropriate carbon price'. Rather than attending to fundamental socio-technical entwinements and thinking in terms of long-term processes of transformative change spanning societal systems, responses may be overly concerned with the 'here and now', circumscribed to patching the existing 'way of doing things', and isolated from broader political and social implications. In this way, the importance of long-term adjustments in lifestyle and practices, norms and culture, ownership and organizational structures, legitimacy and political acceptability, along with the driving role of policy may not always be appreciated. Opportunities to actively break social as well as technical carbon lock-ins (e.g., eroding the endowments of opponents to the low-carbon transition) and build up new low-carbon societal configurations (e.g., by encouraging capacity-building among networks of innovators) may be overlooked in favor of ameliorating established arrangements and trajectories. In other words, there is room to more fully embrace the *pervasive* (changes will not be confined to particular technological artefacts or product supply chains), *protracted* (changes will unfold over multiple decades), and *co-evolutionary* (changes will involve

continuous interactions among social and technical factors) character of the low-carbon transition. In particular, there is room to further reflect the *political* features of low-carbon transitions. That is, how society will: grapple with the distribution of costs and benefits, encourage changes in longstanding practices and lifestyles, build and broaden support for the low-carbon transition, promote the orderly decline of politically and economically important carbon-intensive industries, negotiate among often competing priorities and interests, and navigate technical and institutional choices, among other issues. To be sure, this is not to denigrate the importance of technical and economic responses as these must play an essential role in any credible low-carbon pathway.

Interestingly, a relative emphasis on techno-economic and biophysical dimensions appears to be at odds with how many analysts actually view the core of the climate change problem. Irrespective of research tradition, it is often acknowledged that credible responses to climate change are not so much constrained by technical or economic limits but rather by political and social barriers (Jacobson et al., 2017, 2015). What is of equal interest, then, is how technical and economic responses interface with and might be complemented by social and political forces in constituting low-carbon pathways. Already, analysts are making promising strides to explore these interconnections. The integrated assessment modelling community is, for instance, constructing and drawing upon *shared socio-economic development pathways* to better reflect the social and political dimensions underlying alternative courses of societal development (O'Neill et al., 2017, 2014; Riahi et al., 2017). Similarly, socio-technical transition scholars are moving to enrich perspectives (Geels et al., 2018; Turnheim et al., 2015) as well as more fully incorporate political dynamics (Cherp et al., 2018). As part of this, studies are attempting to tease

out the consequences and tradeoffs of diverging choices for alternative transition pathways (Foxon et al., 2013; Rosenbloom et al., 2018a).

Beyond these considerations, findings also suggest that there may be opportunities to further develop and leverage the functions of pathways (i.e., mapping, planning, learning, bridging, and communicating). Bridging, for instance, has yet to be fully explored. Although the concept of pathways already embraces a series of perspectives, there are still opportunities to bring diverse ideas and approaches together in constructive dialogue (to better represent social and political dimensions, among other aims). A research agenda has recently emerged that investigates opportunities for mutual enrichment surrounding pathways analysis. In particular, growing attention is being paid to: (1) combining analytical approaches (Geels et al., 2018; Turnheim et al., 2015); (2) considering potential ontological and epistemological (mis)alignments among perspectives (Geels et al., 2016a); (3) bringing approaches into dialogue to overcome individual limitations (McDowall, 2014); and (4) integrating different applications (Cherp et al., 2018; Foxon, 2011). These efforts are unfolding both across disciplines (Turnheim et al., 2015; van Sluisveld et al., 2018) and within disciplines (Holtz et al., 2015; Papachristos, 2014). Yet, despite making promising strides to better align approaches, there remain important questions about the extent to which different ideas, models, and approaches might complement each other in devising and assessing low-carbon pathways.

In a similar fashion, findings indicate that the functions of pathways are not always evenly represented. Some approaches emphasize mapping (van Vuuren et al., 2011) or planning (Deep Decarbonization Pathways Project, 2015), whereas others more prominently reflect learning and

bridging (Turnheim et al., 2015). Still others emphasize communicating (UK Government, 2013). This may lend further support to the above research agenda as different perspectives and approaches may have slightly different tendencies and strengths with respect to functions. The results of formal models may, for instance, hold promise in communicating low-carbon transitions by making change processes in natural or human (especially, climate and energy) systems more accessible (depending on model outputs). In contrast, socio-technical models may be better equipped to learn from historical episodes of change and communicate the complex interactions occurring within and even between societal systems. As the first paper of this thesis reveals, imagery has an important place in these efforts. Indeed, a central part of collaborations among different approaches is to capture different dynamics through simulation and visualization (Bergman et al., 2008; Foxon, 2013; Li et al., 2015; McDowall, 2014; Papachristos, 2014). This opens up questions about how pathways approaches might further leverage functional complementarities to better fulfill their role (e.g., by bringing together communication and bridging functions to enrich stakeholder engagement around low-carbon transitions).

3. A core contribution: elucidating the politics of low-carbon pathways

The second core contribution involves elaborating the political dynamics that help shape the socio-technical responses underlying unfolding decarbonization pathways. Connecting with the growing body of research focused on the role of politics and agency within transition processes (Köhler et al., 2019), this thesis argues that attending to political dynamics is a crucial step in understanding how low-carbon pathways open and unfold. In particular, the three studies developed here underscore that *ideas matter in transitions*. According to this research, ideas relate not only to the concepts and categories used to frame the climate challenge (e.g.,

‘pathways’ or ‘resilience’) but also the storylines linked to possible responses (alternative innovations and infrastructures) and contending interests. Concerning the former, this dissertation shows how diverse actors construct meaning around the problem through the interpretation and development of a key environmental concept – i.e., pathways. With respect to the latter, it reveals how contending actors engage in framing struggles over policy and technology responses, modulating the low-carbon possibilities and sequences of choices that link current societal arrangements to future decarbonized states. Consider, for instance, how contending actors framed coal as either a public health crisis or as a pillar of reliability and affordability in order to either prevent or perpetuate its use within future electricity systems. In this fashion, ideas help open or close the envelope of possibilities under consideration, reflecting tensions around perspectives, interests, and material resources. Other studies have also acknowledged framing struggles as a critical means through which actors negotiate the legitimacy of technology and policy responses (Geels and Verhees, 2011; Leipprand and Flachsland, 2018; Rosenbloom et al., 2016, 2018a).

This research program also contributes to the development of two approaches that hold promise for attending to the political dimensions of low-carbon pathways. The first approach, entitled the *multi-dimensional discursive approach* (Rosenbloom et al., 2016b), builds on recent efforts to bring discourse and transition approaches closer together (Bosman et al., 2014; Geels and Verhees, 2011; Leipprand and Flachsland, 2018; Rosenbloom et al., 2016b). This approach understands ideas as a critical political battleground in transition contexts and helps to scrutinize the continual discursive struggles taking place around alternative low-carbon possibilities. It captures how contending actors use their ideational capacities to construct storylines that bring

together claims about the features of innovations and the context in which these innovations diffuse. Further, it shows how storylines present diverging implications for low-carbon pathways. By attending to these dynamics, this approach embraces and weaves together ideas, interests, institutions, and infrastructure. It has been acknowledged as a fruitful complement to transitions perspectives (Kern and Rogge, 2018) and helped inform a range of studies (Falcone et al., 2018; Falcone and Sica, 2019; Leipprand and Flachsland, 2018; Morone et al., 2019).

The second approach is informed by the above discourse-transition crossovers along with the literature on multi-regime interactions (Geels, 2007; Konrad et al., 2008; Papachristos, 2014; Raven, 2007; Raven and Verbong, 2007) and recent debates around disruption (Johnstone and Kivimaa, 2018; Wilson and Tyfield, 2018; Winskel, 2018). Drawing on these perspectives, this dissertation considers how different energy systems (electricity, transport, and heating) and their affiliated actors are interacting around key pillars of low-carbon pathways: expanded societal electrification and electricity trade. It does so by examining actor statements and mapping their positions around potential directions of low-carbon change, distilling general interaction patterns (competitive or symbiotic). This approach provides a way to explore how and why: (1) political actors position themselves with respect to potential steps along possible low-carbon pathways; and (2) these steps may activate alignments or tensions that could be leveraged to accelerate decarbonization. From a governance perspective, this approach may help with the identification of leverage points for further decarbonization or points of friction by capturing how networks of actors are positioning themselves around low-carbon possibilities. This could complement efforts to identify and enact critical choices that help define alternative directions of low-carbon change (Foxon et al., 2013; Rosenbloom et al., 2018a).

Three more general lessons for the theory and governance of low-carbon transitions follow from these efforts. First, the second study of this thesis outlines a series of discursive patterns that mark framing struggles surrounding low-carbon pathways. It shows how storylines that challenge the socio-technical regime can emerge, challenge longstanding logics, and eventually destabilize established trajectories. While framing struggles are likely to be present throughout this process, these struggles can be more or less pronounced. Initially, challenging discourses may only warrant a limited response from incumbents as acknowledging these storylines may serve to validate alternative possibilities – this finding is echoed by other studies (Hajer, 1995b; Rosenbloom et al., 2016). In contrast, discursive contests can become particularly heated when challenging storylines and the disruptive possibilities they suggest begin to build momentum and offer a viable alternative to the existing way of doing things. This not only reflects the coal phase-out experience but also more recent debates around the decline of fossil fuel-based vehicles. Britain, for instance, has stated it will ban the sale of diesel and gas cars by 2040, linking the fossil fuel-based car to critical health and environment concerns (Castle, 2017). France, Germany, India, California, China, and others are either in the midst of contemplating or adopting phase-out plans based on similar logics (Petroff, 2017). In the face of mounting pressure, representatives of the automotive industry have begun to develop concerted responses, linking to ideas about "consumer choice" (Bradsher, 2017; Vaughan, 2017). Despite the long timespan at play here, these proposals (along with the rapid advancement of electric vehicle technology) represent an increasingly serious threat to the longevity of the international auto industry as it exists now. This suggests that the battle over the decline of fossil fuel powered cars is advancing rapidly and framing struggles (as well as positional tensions) are likely to mount as

patterns of actor interaction play out over time. The discursive patterns identified may, therefore, help describe different phases of discursive interaction, directing attention to the continual and active development of contending storylines (how actors connect the content and context of innovations) as well as the implications these storylines hold for low-carbon pathways.

Second, the third study of this thesis delves further into the disruptive implications of particular responses to the climate challenge. This study posits a relationship between the positions of actors around decarbonization strategies and the perceived disruptive impacts these strategies entail. These disruptions may link to specific firm-level concerns but may extend to broader actor networks, market and ownership structures, business models, regulatory frameworks, and so on. Perceived disruptive potential, therefore, relates to the perceptions of individual actors about the degree to which a given climate-energy policy choice (e.g., promoting the electrification of transport) could impact their business models and material holdings (i.e., whether they expect to win or lose under future system conditions). Yet, disruptive potential also concerns the way in which wider constellations of actors perceive their general interests to align (perhaps facilitating the formation of coalitions) or come into tension in the face of particular choices and interactions.

Findings suggest that conflictual (or competitive) patterns of interaction among actors affiliated with electricity, heat, and transport systems are most prominent around the electrification of heat and expanded electricity trade given that these possibilities are perceived to embody sizeable and perhaps more immediate disruptions for dominant interests in Ontario. The electrification of transport, in contrast, has to date seen more limited tensions. While the electrification of

transport implies progressively displacing conventional carbon-intensive fuels, actors have yet to deeply engage with the potential disruptions this could suggest for their business models or the operation of the systems involved over the long-term (note that Ontario is not home to an oil extraction industry). Instead, much of the discourse has focused on mutual benefits for actors affiliated with the electricity and transport systems (e.g., growing sales of electric vehicles, increasing electric vehicle manufacturing in Ontario, and expanding the market for electricity). Perhaps most importantly, however, key actors in the electricity system have placed considerable emphasis on this form of electrification, supporting electric vehicle advocacy and awareness efforts. With this, the prospects of alternative decarbonization responses could be enabled or constrained by the way in which societal actors are strategically positioning themselves, deploying their resources (material and ideational), and mobilizing broader networks.

Third, and more broadly, the final study of this thesis underscores the importance of reengaging with the interactions occurring between (as opposed to within) different socio-technical systems. Societal decarbonization will not only be defined by interactions isolated to single systems (niche-regime dynamics) but will relate to the interface of multiple system configurations (between electricity and heat, for instance). Analysts and policymakers would, therefore, do well to more deeply consider how emerging sites of interaction might open, accelerate, or hinder transition pathways toward decarbonization.

The research program centrally focused in the thesis has also been enriched by, and further explored through, a range of collaborative works completed during the development of this thesis. This body of work has investigated historical development patterns with implications for

the pursuit of future low-carbon pathways (Rosenbloom and Meadowcroft, 2014), the promise of discursive-transition crossovers (Rosenbloom et al., 2016), how pathways thinking might be strengthened by the identification of critical choices leading toward alternative possible low-carbon futures (Rosenbloom et al., 2018a), along with many other related topics surrounding the politics of low-carbon pathways (see Table 1). This work has been acknowledged within the international transitions research agenda (Köhler et al., 2019) and taken up within a range of transitions studies (e.g., Cherp et al., 2018; Geels, 2018; Markard, 2018).

Table 1: Collaborative works completed during the development of this thesis

Collaborative works	Key themes
Berton, H., Rosenbloom, D., Temby, O., Meadowcroft, J., 2015. Using local improvement charges to finance solar photovoltaic systems. Energy Studies Review 22, 95–110. https://doi.org/10.15173/esr.v22i1.3308	Local climate-energy policy and planning; emerging renewable energy possibilities
Mallett, A., Jegen, M., Philion, X.D., Reiber, R., Rosenbloom, D., 2018. Smart grid framing through coverage in the Canadian media: Technologies coupled with experiences. Renewable and Sustainable Energy Reviews 82, 1952–1960. https://doi.org/10.1016/j.rser.2017.06.013	Framing and legitimacy struggles in transitions; smart grid technologies
Rosenbloom, D., Berton, H., Meadowcroft, J., 2016. Framing the sun: a discursive approach to understanding multi-dimensional interactions within socio-technical transitions through the case of solar electricity in Ontario, Canada. Research Policy 45, 1275–1290. https://doi.org/10.1016/j.respol.2016.03.012	Discourse-transition complementarities; framing and legitimacy struggles in transitions; emerging renewable energy possibilities
Rosenbloom, D., Haley, B., Meadowcroft, J., 2018. Critical choices and the politics of decarbonization pathways: exploring branching points surrounding low-carbon transitions in Canadian electricity systems. Energy Research & Social Science 37, 22–36. https://doi.org/10.1016/j.erss.2017.09.022	Branching points and critical choices; framing and legitimacy struggles in transitions; future electricity system change
Rosenbloom, D., Meadowcroft, J., 2014. The	Historical electricity system change; future

journey towards decarbonization: exploring socio-technical transitions in the electricity sector in the province of Ontario (1885–2013) and potential low-carbon pathways. Energy Policy 65, 670–679. https://doi.org/10.1016/j.enpol.2013.09.039	electricity system change; political contestation over possible models of change
Rosenbloom, D., Meadowcroft, J., 2014. Harnessing the sun: reviewing the potential of solar photovoltaics in Canada. Renewable and Sustainable Energy Reviews 40, 488–496. https://doi.org/10.1016/j.rser.2014.07.135	Emerging renewable energy possibilities; assessing socio-technical potential
Rosenbloom, D., Meadowcroft, J., Cashore, B., 2019. Stability and climate policy? Harnessing insights on path dependence, policy feedback, and transition pathways. Energy Research & Social Science 50, 168–178. https://doi.org/10.1016/j.erss.2018.12.009	Climate-energy policy challenges and opportunities; policy stability and stickiness
Rosenbloom, D., Meadowcroft, J., Sheppard, S., Burch, S., Williams, S., 2018. Transition experiments: Opening up low-carbon transition pathways for Canada through innovation and learning. Canadian Public Policy 44, 1–16. https://doi.org/10.3138/cpp.2018-020	The role of experimentation and learning-by-doing
Temby, O., Kapsis, K., Berton, H., Rosenbloom, D., Gibson, G., Athienitis, A., Meadowcroft, J., 2014. Building-Integrated Photovoltaics: Distributed Energy Development for Urban Sustainability. Environment: Science and Policy for Sustainable Development 56, 4–17. https://doi.org/10.1080/00139157.2014.964092	Emerging renewable energy possibilities

4. Lessons for transition policy and practice

Beyond these core contributions, this research has also generated a series of lessons for policy and practice. While a range of insights have been developed within each of the individual studies, here I distill four with particular relevance for accelerating the low-carbon transition. First, findings lend strength to the body of evidence that is mounting in favor of adopting diverse portfolios of policy measures (e.g., sector-specific regulations and incentives) as opposed to relying solely on market-based policies (e.g., carbon taxes) to address the climate challenge

(Ball, 2018; Jaccard, 2016; Tvinnereim and Mehling, 2018). The coal phase-out example corroborates the fact that regulatory approaches may have success where carbon pricing regimes encounter political backlash. Despite the relative efficiency of market-based approaches, they have faced harsh criticism from opponents in Canada and elsewhere. Consider, for instance, how politicians at both provincial and federal levels of government have referred to carbon pricing as a "tax grab" (Crawley, 2018; Gilmore, 2018). Despite some mixed indications of support among the public (Akin, 2019; Beugin et al., 2018), there remain important cleavages regarding the political acceptability of carbon pricing. Take, for example, a recent poll that found 7 out of 10 Ontarians believe carbon taxes to be a "tax grab" and would do little to reduce GHG emissions (Kalvapalle, 2018). Consider also the increasingly prominent rallies in Alberta calling for the reversal of Federal carbon pricing legislation (CBC News, 2018; The Canadian Press, 2018). This opposition to carbon pricing has begun to translate into votes as Ontario has elected a majority Conservative government who campaigned on dismantling the province's cap-and-trade system. Other provinces appear poised to follow suit (Alberta), have backpedalled on their carbon pricing commitments (Manitoba), or continue to voice vehement opposition (Saskatchewan). In the face of this political backlash, governments in Canada and abroad may have an interest in placing greater emphasis on policy mixes as they seek to ramp up action and meet climate commitments.

Second, the coal phase-out case reveals that low-carbon pathways may open and be enacted as a result of broader societal benefits. The case suggests that the health-related concerns played an integral role in encouraging the adoption of the phase-out. However, air quality and health considerations did not drive the full implementation of the phase-out. Rather, a complex and

evolving set of priorities helped shape the coal phase-out. So, while health concerns may have played an important role, climate and reliability considerations modulated the direction of change. This points to the fact that low-carbon pathways are likely to be tied to both carbon constraints but also an array of other societal motivations. Industrial development, health, convenience, and regional environmental priorities can all be interwoven with and help drive decarbonization pathways. Consider, for instance, how China's recent shift in climate policy has been linked to climate engagement but also health and air quality issues as well as efforts to improve its global image and capture the growing clean technology market (Pope, 2018). Similarly, heath and regional environmental concerns appear to be of equal importance to climate considerations within the emerging fossil fuel phase outs (e.g., coal-fired power but also gasoline cars) taking place internationally. Together, this reinforces the fact that the response to climate change is not developing in isolation from other societal priorities. Indeed, low-carbon pathways are fundamentally about moving toward a *desirable as well as low-carbon* future.

Third, the framing struggles around the coal phase-out point to potential strategies for actors engaged in narrative work aimed at accelerating low-carbon transitions. The second study indicates that proponents of the coal phase-out developed narratives that communicated *compelling yet simplified understandings of complex problems*. In this way, these actors conveyed the essential elements of the challenge without being impeded by the stubborn factors involved in air quality issues, climate change, or the operation of the electricity system. This made the problems seem more tractable, opening up possible responses that were perceived as having real and immediate impacts (phasing out coal would combat smog-related health issues and climate change). Narratives also focused on coal and not all sources of air and climate

pollutants, *painting a single target as the villain*. In this fashion, proponents invoked longstanding symbols (heroes, villains, and victims) that appealed to average Canadians and suggested concrete opportunities for action. Although several considerations shaped the phase-out experience, the discursive patterns uncovered in the second study suggest that there is potential to provoke accelerated action by *appealing to more tangible and proximate issues* (health risks and smog). And, while the stakes may be high during the initial framing struggles, *persistent discursive work is required to update narratives and press for the achievement of outcomes over the long-term*.

These lessons might be translated to broader climate policy debate, offering practitioners and policymakers interested in accelerating low-carbon transitions opportunities to enhance their own narrative work. Findings underscore the importance of: creating compelling problem frames (e.g., the idea of a transition); targeting the villains (e.g., fossil fuel vehicles) and developing solutions that have a coherent rationale (e.g., gradually phasing out fossil fuel vehicles while ramping up adoption of zero emissions vehicles over the course of the transition); bringing out the tangible and proximate benefits of action (e.g., improved convenience); and, continuously renewing narrative strategies.

Fourth, examining actor positions around the 2017 Long-term Energy Plan may suggest that there is room for greater ambition around the adoption of electric vehicles in Ontario. Findings indicate that there are presently greater potential alignments among energy systems and affiliated actors around this climate response. There is particularly strong support for this form of electrification among incumbent and emerging actors in the electricity system along with

prominent environmental advocacy groups (some of whom were central to the coal phase-out). Given the historical strength of the electricity regime in Ontario and its importance for economic development (Rosenbloom and Meadowcroft, 2014) as well as the ideational resources of environmental advocates (Rosenbloom, 2018), this group of actors may form the foundation for a stronger and more compelling push around the electrification of transport. As the provincial Conservative government has rejected carbon pricing, societal actors may advocate policy measures promoting additional electric vehicle manufacturing capacity in Ontario, establishing an electric vehicle sales standard, or even signalling the long-term phase-out of fossil fuel vehicles (as is the case in Britain and France, for example). Calls for the electrification of transport could be framed in terms of "industrial renewal" for Ontario's flagging vehicle manufacturing industry (Meckling and Nahm, 2019). To be sure, the electrification of transport may also manifest in other ways (e.g., mass transit or autonomous modalities) and compelling narratives may develop around these alternatives (e.g., tying into cultural shifts around vehicle ownership).

5. Final remarks and future directions

This discussion has highlighted the core contributions and practical insights flowing from this dissertation research, which have helped to advance the state of knowledge around transitions theory, the Canadian transition context, as well as policy and practice aimed at accelerating low-carbon transitions. In particular, this work has interrogated the concept of pathways in the context of low-carbon transitions and further elucidated how politics help shape unfolding processes of decarbonization. Contemplating the climate challenge in terms of pathways has not only encouraged a greater understanding of how sequences of choices link current societal

arrangements to low-carbon futures but has also shed light on the multiple dimensions that will need to undergo change as part of this process. Exploring the political dynamics of pathways has revealed how contending actors intervene to modulate responses and help shape alternative directions of change. As part of this, discursive-transition approaches have been mobilized and extended to attend more closely to framing struggles surrounding policy and technology. The case studies developed here also offer a number of useful examples that provide lessons for addressing the climate challenge.

5.1 Research limitations

Despite these important contributions, this research also has some limitations. One potential weakness relates to the reliance on written sources. While efforts were made to triangulate data collection from multiple sources (e.g., energy data, scholarly works, media articles, consultation submissions, as well as government and industry reports), other data sources and methods could have complemented the research approach. Interviews with key informants, in particular, were considered as they could have provided additional insight into the narratives and positions employed by actors in the second and third study. A decision was taken not to conduct interviews as part of these studies for the following reasons. In regard to the second study, rich empirically-focused work based on extensive interviews had already been carried out that revealed the perspectives of the key actors involved in Ontario's coal phase-out (Harris et al., 2015). Replicating this work would have required considerable time and resources without making a novel contribution to the literature. So, rather than strive for replication, the second study was informed by and sought to build on earlier work.

With respect to the third study, carrying out interviews would have posed a more complicated series of challenges. First, this study focused on interactions among three different energy systems and, in this way, had to sacrifice some empirical depth for breadth of coverage (54 key actors were identified). Second, it was expected that interview participation would have been uneven among these actors given the politically contested nature of the electricity file in Ontario during the period under study. This uneven representation was encountered by other studies examining the electricity system in Ontario at the same time. Brisbois (2019), for instance, reported that the Power Workers' Union and provincial bureaucracy declined interview requests related to the 2017 Long-term Energy Plan. Third, it could also be expected that interview participants (even if anonymized) would not have been willing to have their responses attributed to their organizations. As a result, it may not have been possible to associate particular positions and narratives with specific policy actors – a central part of the analytical approach and objectives. Lastly, it is arguable as to whether interviews would have returned substantially different positions and narratives from those represented in written sources (consultation submissions, media articles, and public commentary). Mordue (2017), for instance, carried out interviews with executives in the automotive industry in Ontario and found that the industry largely sees its role in the electricity system as that of a large electricity consumer, emphasizing concerns about electricity costs. This lends support to my findings, which suggest that the industry focused on immediate concerns about the cost of electricity during the consultation rather than far-flung possibilities relating to the electrification of transport. Yet, even so, interviews may have helped to further tease out the position of actors in the automotive industry in regard to these possibilities. This represents fruitful terrain for future research, which could help to enrich the findings presented here.

This research is also exploratory and interpretive in nature. As described in the research approach (see Section 5 of the Introduction), steps have therefore been taken to cross-check findings by exposing them to expert opinion through discussions with committee members, consultations with conference and workshop participants, and the peer-review process. This deliberately iterative process introduced opportunities to continually revisit and revise interpretations. Moreover, the exploratory orientation of this research aligns with the phenomenon of interest: the complex and emergent political properties of unfolding low-carbon pathways.

Perhaps most importantly, however, this research is but one small part of a broader research agenda aimed at enriching the theory and governance of low-carbon transitions. Given the scale and scope of reorienting societal systems toward decarbonization, this work alone cannot hope to fully answer the research questions. Rather, it builds on the work of others and begins to respond to and shed light on the phenomenon of interest. Much still remains to be done. Nevertheless, this dissertation makes a series of contributions to knowledge surrounding low-carbon transitions, lends strength to existing research agendas (e.g., the politics of transitions), and points to new areas of inquiry.

5.2 Future directions

From this, several future research directions are of particular relevance. First, there are opportunities to explore additional good examples surrounding the politics of low-carbon pathways and move toward cross-case comparisons. Although transition studies have begun to

attend much more carefully to the political dimensions of the climate challenge (e.g., Bosman et al., 2014; Kern, 2012; Markard et al., 2016; Rosenbloom and Meadowcroft, 2014; Verhees et al., 2015), there is still room to deepen the body of evidence and lessons upon which scholars can draw. Doing so would allow analysts to refine transition perspectives and approaches, compare experiences across contexts, and gain additional analytical traction on the climate challenge. Some promising cases to explore could revolve around other emerging fossil fuel phase-out experiences (around coal power or gas cars) as well as historical episodes of decline more generally (Turnheim and Geels, 2012).

Second, there may be additional opportunities to compare and contrast pathways with other prominent concepts for thinking about and acting upon the future such as scenarios, visions, imaginaries, and so on. Some work has taken steps in this direction (Hofman et al., 2004; Rosenbloom et al., 2018a). However, there is still room to further tease out the complementarities and differences among these concepts. Third, there may be considerable merit in exploring the processes and procedures used to generate and analyze low-carbon pathways. That is, what are the relative strengths and limitations of visioning exercises (Kemp et al., 2007), formal modelling (Bataille et al., 2016; Layzell and Beaumier, 2018), narrative scenarios (Miller et al., 2015; Moezzi et al., 2017), visualization (Shaw et al., 2009; Sheppard et al., 2011), structured decision tasks (Bessette et al., 2014), serious games (Holtz et al., 2015), among other approaches for informing pathways analysis? Moreover, how might these different procedures and methods complement or conflict with one another in this process? Fourth, it would be useful to develop tools and indicators for assessing the functions of low-carbon pathways that are being

practically applied to reorient societal systems at multiple scales (at the level of local communities, specific sectors, or nations).

Lastly, there are a series of broader questions that present themselves about the politics of transitions. As Meadowcroft (2011, p. 73) reminds us, there is merit in exploring "how political actors (understood broadly) can construct linkages between economic, social and environmental reform agendas;[…] which strategies are most successful for building impetus for reform in specific societal subsystems; what forms of political alliance are most conducive to encouraging sustainability transitions; which kinds of reform create positive feedbacks driving further reform; and what resistance strategies are most popular with transition opponents [and] how they can be countered by proponents". These are only a few of the many directions presented by this work. And so, despite having advanced the state of knowledge around pathways and politics in the context of low-carbon transitions, this is only the beginning of the journey.

Akin, D., 2019. Ottawa's unpublished internal polls on federal carbon tax give edge to Trudeau [WWW Document]. Glob. News. URL https://globalnews.ca/news/4811385/ottawas-unpublished-internal-polls-carbon-tax-trudeau/ (accessed 1.4.19).

Arthur, W.B., Ermoliev, Y.M., Kaniovski, Y.M., 1987. Path-dependent processes and the emergence of macro-structure. Eur. J. Oper. Res. 30, 294–303.

Ascui, F., Lovell, H., 2011. As frames collide: making sense of carbon accounting. Account. Audit. Account. J. 24, 978–999. https://doi.org/10.1108/09513571111184724

Asquith, M., Backhaus, J., Geels, F.W., Golland, A., Kemp, R., Lung, T., O'Brien, K., Steward, F., Strasser, T., 2017. Perspectives on transitions to sustainability. European Environment Agency, Copenhagen.

Audet, R., 2016. Transition as discourse. Int. J. Sustain. Dev. 19, 365–382.

Avelino, F., Grin, J., Pel, B., Jhagroe, S., 2016. The politics of sustainability transitions. J. Environ. Policy Plan. 18, 557–567. https://doi.org/10.1080/1523908X.2016.1216782

Ball, J., 2018. Hot Air Won't Fly: The New Climate Consensus That Carbon Pricing Isn't Cutting It. Joule 2, 2491–2494. https://doi.org/10.1016/j.joule.2018.11.019

Bataille, C., Waisman, H., Colombier, M., Segafredo, L., Williams, J., Jotzo, F., 2016. The need for national deep decarbonization pathways for effective climate policy. Clim. Policy 16, S7–S26. https://doi.org/10.1080/14693062.2016.1173005

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., Rickne, A., 2008. Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. Res. Policy 37, 407–429. https://doi.org/10.1016/j.respol.2007.12.003

Berggren, C., Magnusson, T., Sushandoyo, D., 2015. Transition pathways revisited: Established firms as multi-level actors in the heavy vehicle industry. Res. Policy 44, 1017–1028. https://doi.org/10.1016/j.respol.2014.11.009

Bergman, N., Haxeltine, A., Whitmarsh, L., Köhler, J., Schilperoord, M., Rotmans, J., 2008. Modelling socio-technical transition patterns and pathways. J. Artif. Soc. Soc. Simul. 11, 7.

Berkhout, F., 2008. Innovation theory and socio-technical transitions, in: Bergh, J.C.J.M.V.D., Bruinsma, F.R. (Eds.), Managing the Transition to Renewable Energy; Theory and Macro/Regional Practice. Edward Elgar, Cheltenham, UK ; Northampton, MA.

Berkhout, F., 2002. Technological regimes, path dependency and the environment. Glob. Environ. Change 12, 1–4.

Berkhout, F., Smith, A., Stirling, A., 2004. Socio-technological regimes and transition contexts, in: System Innovation and the Transition to Sustainability: Theory, Evidence and Policy. Edward Elgar, Cheltenham, pp. 48–75.

Bessette, D.L., Arvai, J., Campbell-Arvai, V., 2014. Decision Support Framework for Developing Regional Energy Strategies. Environ. Sci. Technol. 48, 1401–1408. https://doi.org/10.1021/es4036286

Beugin, D., Frank, B., Hodgson, G., Lipsey, R., Olewiler, N., Ragan, C., 2018. Clearing the air: how carbon pricing helps Canada fight climate change. Ecofiscal Commission, Montreal.

Bijker, W.E., Hughes, T.P., Pinch, T.J. (Eds.), 1987. The Social construction of technological systems: new directions in the sociology and history of technology. MIT Press, Cambridge.

Bloomberg New Energy Finance, 2018. Global Trends in Renewable Energy Investment 2018. Frankfurt School-UNEP Centre/BNEF, Frankfurt.

Bosman, R., Loorbach, D., Frantzeskaki, N., Pistorius, T., 2014. Discursive regime dynamics in the Dutch energy transition. Environ. Innov. Soc. Transit. 13, 45–59. https://doi.org/10.1016/j.eist.2014.07.003
Bosman, R., Rotmans, J., 2016. Transition governance towards a bioeconomy: a comparison of Finland and The Netherlands. Sustainability 8, 1017. https://doi.org/10.3390/su8101017
BP, 2017. BP Energy Outlook 2017. BP p.l.c., London.
Bradsher, K., 2017. G.M. chief, in China, challenges planned bans of gasoline cars. N. Y. Times.
Brisbois, M.C., 2019. Powershifts: A framework for assessing the growing impact of decentralized ownership of energy transitions on political decision-making. Energy Res. Soc. Sci. 50, 151–161. https://doi.org/10.1016/j.erss.2018.12.003
Brown, H.S., Vergragt, P.J., 2008. Bounded socio-technical experiments as agents of systemic change: The case of a zero-energy residential building. Technol. Forecast. Soc. Change 75, 107–130. https://doi.org/10.1016/j.techfore.2006.05.014
C2ES, 2017. Global Emissions [WWW Document]. Cent. Clim. Energy Solut. URL https://www.c2es.org/content/international-emissions/ (accessed 7.26.18).
Candy, S., Larsen, K., Twomey, P., McGrail, S., Ryan, C., 2017. Pathways 2040: results from Visions and pathways 2040 : scenarios and pathways to low carbon living. Victorian Eco-Innovation Lab, Melbourne.
Castle, S., 2017. Britain to Ban New Diesel and Gas Cars by 2040 [WWW Document]. N. Y. Times. URL https://www.nytimes.com/2017/07/26/world/europe/uk-diesel-petrol-emissions.html
CBC News, 2018. Albertans rally against "problematic" Bill C-69 [WWW Document]. CBC News. URL https://www.cbc.ca/news/canada/calgary/alberta-bill-c69-rally-1.4859917 (accessed 1.3.19).
Center for International Environmental Law, 2017. Fueling Plastics: Fossils, Plastics, and Petrochemical Feedstocks. CIEL, Washington, D.C.
Ceschin, F., fabrizio. ceschin@brunel.ac. u., 2014. How the design of socio-technical experiments can enable radical changes for sustainability. Int. J. Des. 8, 1–21.
Cherp, A., Vinichenko, V., Jewell, J., Brutschin, E., Sovacool, B.K., 2018. Integrating techno-economic, socio-technical and political perspectives on national energy transitions: A meta-theoretical framework. Energy Res. Soc. Sci. 37, 175–190. https://doi.org/10.1016/j.erss.2017.09.015
Coenen, L., Benneworth, P., Truffer, B., 2012. Toward a spatial perspective on sustainability transitions. Res. Policy 41, 968–979. https://doi.org/10.1016/j.respol.2012.02.014
Cotton, M., Rattle, I., Van Alstine, J., 2014. Shale gas policy in the United Kingdom: An argumentative discourse analysis. Energy Policy 73, 427–438. https://doi.org/10.1016/j.enpol.2014.05.031
Crawley, M., 2018. Ontario PC leadership rivals scrap carbon tax from platform [WWW Document]. CBC News. URL http://www.cbc.ca/news/canada/toronto/caroline-mulroney-doug-ford-christine-elliott-carbon-tax-1.4524469 (accessed 5.9.18).
Curran, G., 2012. Contested energy futures: Shaping renewable energy narratives in Australia. Glob. Environ. Change 22, 236–244. https://doi.org/10.1016/j.gloenvcha.2011.11.009
Deep Decarbonization Pathways Project, 2015. Pathways to deep decarbonization 2015 report. SDSN - IDDRI.

Dosi, G., 1982. Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change. Res. Policy 11, 147–162.
Dosi, G., Freeman, C., Nelson, R., Silverberg, G., Soete, L., 1988. Technical Change and Economic Theory (LEM Book Series). Laboratory of Economics and Management (LEM), Sant'Anna School of Advanced Studies, Pisa.
Dryzek, J.S., 2012. The Politics of the Earth: Environmental Discourses, Third Edition edition. ed. Oxford University Press, Oxford.
Dryzek, J.S., 2006. Deliberative global politics: discourse and democracy in a divided world. Polity, Cambridge.
Dryzek, J.S., 1990. Discursive democracy : politics, policy, and political science. Cambridge ; New York : Cambridge University Press.
Eames, M., Mcdowall, W., Hodson, M., Marvin, S., 2006. Negotiating contested visions and place-specific expectations of the hydrogen economy. Technol. Anal. Strateg. Manag. 18, 361–374. https://doi.org/10.1080/09537320600777127
Environment and Climate Change Canada, 2016. Canada's mid-century long-term low-greenhouse gas development strategy. Government of Canada, Ottawa.
European Commission, 2011. A roadmap for moving to a competitive low carbon economy in 2050. Brussels.
Falcone, P.M., Morone, P., Sica, E., 2018. Greening of the financial system and fuelling a sustainability transition: A discursive approach to assess landscape pressures on the Italian financial system. Technol. Forecast. Soc. Change 127, 23–37. https://doi.org/10.1016/j.techfore.2017.05.020
Falcone, P.M., Sica, E., 2019. Assessing the Opportunities and Challenges of Green Finance in Italy: An Analysis of the Biomass Production Sector. Sustainability 11, 517. https://doi.org/10.3390/su11020517
Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, 2016. Climate Action Plan 2050 – Principles and goals of the German government's climate policy. BMUB, Berlin.
Figueres, C., Schellnhuber, H.J., Whiteman, G., Rockström, J., Hobley, A., Rahmstorf, S., 2017. Three years to safeguard our climate. Nat. News 546, 593.
Fischer, E.M., Knutti, R., 2015. Anthropogenic contribution to global occurrence of heavy-precipitation and high-temperature extremes. Nat. Clim. Change 5, 560–564. https://doi.org/10.1038/nclimate2617
Fischer, F., 2003. Interpretive public policy: Normative frames and methodological issues, in: Fischer, F. (Ed.), Reframing Public Policy. Oxford University Press, Oxford.
Fischer, F., Forester, J. (Eds.), 1993. The Argumentative Turn in Policy Analysis and Planning. Duke University Press, Durham.
Flyvbjerg, B., 2006. Five Misunderstandings About Case-Study Research. Qual. Inq. 12, 219–245. https://doi.org/10.1177/1077800405284363
Flyvbjerg, B., 2001. Making Social Science Matter: Why social inquiry fails and how it can succeed again. Cambridge University Press, Cambridge.
Folke, C., 2006. Resilience: The emergence of a perspective for social–ecological systems analyses. Glob. Environ. Change 16, 253–267. https://doi.org/10.1016/j.gloenvcha.2006.04.002

Foxon, T.J., 2013. Transition pathways for a UK low carbon electricity future. Energy Policy 52, 10–24. https://doi.org/10.1016/j.enpol.2012.04.001
Foxon, T.J., 2011. A coevolutionary framework for analysing a transition to a sustainable low carbon economy. Ecol. Econ. 70, 2258–2267. https://doi.org/10.1016/j.ecolecon.2011.07.014
Foxon, T.J., 2002. Technological and institutional 'lock-in' as a barrier to sustainable innovation. Imperial College Centre for Energy Policy and Technology, London.
Foxon, T.J., Pearson, P.J.G., Arapostathis, S., Carlsson-Hyslop, A., Thornton, J., 2013. Branching points for transition pathways: assessing responses of actors to challenges on pathways to a low carbon future. Energy Policy 52, 146–158. https://doi.org/10.1016/j.enpol.2012.04.030
Freeman, C., 1987. Technology, policy, and economic performance: lessons from Japan. Pinter Publishers.
Fuenfschilling, L., Truffer, B., 2014. The structuration of socio-technical regimes—Conceptual foundations from institutional theory. Res. Policy 43, 772–791. https://doi.org/10.1016/j.respol.2013.10.010
Fuss, S., Canadell, J.G., Peters, G.P., Tavoni, M., Andrew, R.M., Ciais, P., Jackson, R.B., Jones, C.D., Kraxner, F., Nakicenovic, N., Le Quéré, C., Raupach, M.R., Sharifi, A., Smith, P., Yamagata, Y., 2014. Betting on negative emissions. Nat. Clim. Change 4, 850–853. https://doi.org/10.1038/nclimate2392
G7, 2015. Think ahead. Act together. Leader's declaration. Group of seven, Elmau.
G8, 2008. Chair's Report to the G8 Hokkaido Toyako Summit: Gleneagles-Dialogue on Climate Change, Clean Energy and Sustainable Development. Group of eight, Tōyako.
Gamson, W.A., Croteau, D., Hoynes, W., Sasson, T., 1992. Media Images and the Social Construction of Reality. Annu. Rev. Sociol. 18, 373–393. https://doi.org/10.1146/annurev.so.18.080192.002105
Gamson, W.A., Modigliani, A., 1989. Media discourse and public opinion on nuclear power: A constructionist approach. Am. J. Sociol. 1–37.
Ganowski, S., Gaede, J., Rowlands, I.H., 2018. Hot off the press! A comparative media analysis of energy storage framing in Canadian newspapers. Energy Res. Soc. Sci. 46, 155–168. https://doi.org/10.1016/j.erss.2018.06.011
Geels, F.W., 2018. Disruption and low-carbon system transformation: Progress and new challenges in socio-technical transitions research and the Multi-Level Perspective. Energy Res. Soc. Sci. 37, 224–231. https://doi.org/10.1016/j.erss.2017.10.010
Geels, F.W., 2014. Regime resistance against low-carbon transitions: introducing politics and power into the multi-level perspective. Theory Cult. Soc. 31, 21–40. https://doi.org/10.1177/0263276414531627
Geels, F.W., 2011. The multi-level perspective on sustainability transitions: Responses to seven criticisms. Environ. Innov. Soc. Transit. 1, 24–40. https://doi.org/10.1016/j.eist.2011.02.002
Geels, F.W., 2010. Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. Res. Policy 39, 495–510. https://doi.org/10.1016/j.respol.2010.01.022
Geels, F.W., 2007. Analysing the breakthrough of rock 'n' roll (1930–1970) Multi-regime interaction and reconfiguration in the multi-level perspective. Technol. Forecast. Soc. Change 74, 1411–1431. https://doi.org/10.1016/j.techfore.2006.07.008

Geels, F.W., 2006. Major system change through stepwise reconfiguration: A multi-level analysis of the transformation of American factory production (1850–1930). Technol. Soc. 28, 445–476. https://doi.org/10.1016/j.techsoc.2006.09.006
Geels, F.W., 2005a. The dynamics of transitions in socio-technical systems: a multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860–1930). Technol. Anal. Strateg. Manag. 17, 445–476.
Geels, F.W., 2005b. Co-evolution of technology and society: The transition in water supply and personal hygiene in the Netherlands (1850–1930)—a case study in multi-level perspective. Technol. Soc. 27, 363–397. https://doi.org/10.1016/j.techsoc.2005.04.008
Geels, F.W., 2005c. Technological Transitions and System Innovations. Edward Elgar Publishing. https://doi.org/10.4337/9781845424596
Geels, F.W., 2004. From sectoral systems of innovation to socio-technical systems. Res. Policy 33, 897–920. https://doi.org/10.1016/j.respol.2004.01.015
Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Res. Policy 31, 1257–1274.
Geels, F.W., Berkhout, F., van Vuuren, D.P., 2016a. Bridging analytical approaches for low-carbon transitions. Nat. Clim. Change 6, 576–583. https://doi.org/10.1038/nclimate2980
Geels, F.W., Kemp, R., 2007. Dynamics in socio-technical systems: Typology of change processes and contrasting case studies. Technol. Soc. 29, 441–455. https://doi.org/10.1016/j.techsoc.2007.08.009
Geels, F.W., Kern, F., Fuchs, G., Hinderer, N., Kungl, G., Mylan, J., Neukirch, M., Wassermann, S., 2016b. The enactment of socio-technical transition pathways: A reformulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990–2014). Res. Policy 45, 896–913. https://doi.org/10.1016/j.respol.2016.01.015
Geels, F.W., McMeekin, A., Pfluger, B., 2018. Socio-technical scenarios as a methodological tool to explore social and political feasibility in low-carbon transitions: Bridging computer models and the multi-level perspective in UK electricity generation (2010–2050). Technol. Forecast. Soc. Change. https://doi.org/10.1016/j.techfore.2018.04.001
Geels, F.W., Schot, J., 2007. Typology of sociotechnical transition pathways. Res. Policy 36, 399–417. https://doi.org/10.1016/j.respol.2007.01.003
Geels, F.W., Sovacool, B.K., Schwanen, T., Sorrell, S., 2017a. Sociotechnical transitions for deep decarbonization. Science 357, 1242–1244. https://doi.org/10.1126/science.aao3760
Geels, F.W., Sovacool, B.K., Schwanen, T., Sorrell, S., 2017b. The Socio-Technical Dynamics of Low-Carbon Transitions. Joule 1, 463–479. https://doi.org/10.1016/j.joule.2017.09.018
Geels, F.W., Verhees, B., 2011. Cultural legitimacy and framing struggles in innovation journeys: A cultural-performative perspective and a case study of Dutch nuclear energy (1945–1986). Technol. Forecast. Soc. Change 78, 910–930. https://doi.org/10.1016/j.techfore.2010.12.004
Genus, A., Coles, A.-M., 2008. Rethinking the multi-level perspective of technological transitions. Res. Policy 37, 1436–1445. https://doi.org/10.1016/j.respol.2008.05.006
Gerring, J., 2011. Case Study: what it is and what it does, in: Goodin, R.E. (Ed.), The Oxford Handbook of Political Science. Oxford University Press, Oxford, p. 40.
Giddens, A., 1984. The Constitution of Society: Outline of the Theory of Structuration. University of California Press.

Gilmore, R., 2018. Poilievre slams feds' carbon pricing report as House debates levy [WWW Document]. iPolitics. URL https://ipolitics.ca/2018/05/01/poilievre-slams-feds-carbon-pricing-report-as-house-debates-levy/ (accessed 5.9.18).
Greenpeace International, European Renewable Energy Council, 2007. Energy [r]evolution: A sustainable world energy outlook. Greenpeace International and EREC, Amsterdam.
Grin, J., Rotmans, J., Schot, J., 2011a. From persistent problems to system innovations and transitions, in: Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change. Routledge, New York, pp. 1–8.
Grin, J., Rotmans, J., Schot, J., 2011b. Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change, 1 edition. ed. Routledge, New York London.
Hajer, M.A., 2006. Doing discourse analysis: coalitions, practices, meaning, in: van den Brink, M., Metze, T. (Eds.), Words Matter in Policy and Planning: Discourse Theory and Method in the Social Sciences. Netherlands Geographical Studies, Utrecht, Netherlands.
Hajer, M.A., 1995. The Politics of Environmental Discourse: Ecological Modernization and the Policy Process. Clarendon Press.
Hajer, M.A., 1993. Discourse coalitions and the institutionalization of practice: The case of acid rain in Britain, in: Fischer, F., Forester, J. (Eds.), The Argumentative Turn in Policy Analysis and Planning. Duke University Press, Durham, pp. 43–76.
Hajer, M.A., Versteeg, W., 2005. A decade of discourse analysis of environmental politics: Achievements, challenges, perspectives 7, 175–184.
Haley, B., 2015. Low-carbon innovation from a hydroelectric base: the case of electric vehicles in Québec. Environ. Innov. Soc. Transit. 14, 5–25. https://doi.org/10.1016/j.eist.2014.05.003
Haley, B., 2011. From staples trap to carbon trap: Canada's peculiar form of carbon lock-in. Stud. Polit. Econ. 88, 97–132. https://doi.org/10.1080/19187033.2011.11675011
Harris, M., Beck, M., Gerasimchuk, I., 2015. The End of Coal: Ontario's coal phase-out.
Hasegawa, T., Fujimori, S., Shin, Y., Takahashi, K., Masui, T., Tanaka, A., 2014. Climate change impact and adaptation assessment on food consumption utilizing a new scenario framework. Environ. Sci. Technol. 48, 438–445. https://doi.org/10.1021/es4034149
Hayhoe, K., Cayan, D., Field, C.B., Frumhoff, P.C., Maurer, E.P., Miller, N.L., Moser, S.C., Schneider, S.H., Cahill, K.N., Cleland, E.E., Dale, L., Drapek, R., Hanemann, R.M., Kalkstein, L.S., Lenihan, J., Lunch, C.K., Neilson, R.P., Sheridan, S.C., Verville, J.H., 2004. Emissions pathways, climate change, and impacts on California. Proc. Natl. Acad. Sci. U. S. A. 101, 12422–12427. https://doi.org/10.1073/pnas.0404500101
Hekkert, M.P., Negro, S.O., 2009. Functions of innovation systems as a framework to understand sustainable technological change: Empirical evidence for earlier claims. Technol. Forecast. Soc. Change, Evolutionary Methodologies for Analyzing Environmental Innovations and the Implications for Environmental Policy 76, 584–594. https://doi.org/10.1016/j.techfore.2008.04.013
Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Kuhlmann, S., Smits, R.E.H.M., 2007. Functions of innovation systems: A new approach for analysing technological change. Technol. Forecast. Soc. Change 74, 413–432. https://doi.org/10.1016/j.techfore.2006.03.002
Hess, D.J., 2016. The politics of niche-regime conflicts: Distributed solar energy in the United States. Environ. Innov. Soc. Transit. 19, 42–50. https://doi.org/10.1016/j.eist.2015.09.002

Hildén, M., Jordan, A., Huitema, D., 2017. Special issue on experimentation for climate change solutions editorial: The search for climate change and sustainability solutions - The promise and the pitfalls of experimentation. J. Clean. Prod. 169, 1–7. https://doi.org/10.1016/j.jclepro.2017.09.019

Hoffmann, M.J., 2012. Climate governance experiments, in: Dauvergne, P. (Ed.), Handbook of Global Environmental Politics. Edward Elgar Publishing, Cheltenham, UK; Northampton, MA, pp. 235–248.

Hofman, P.S., Elzen, B., Geels, F.W., 2004. Sociotechnical scenarios as a new policy tool to explore system innovations: Co-evolution of technology and society in the Netherlands electricity domain. Innov. Manag. Policy Pract. 6, 344–360. https://doi.org/10.5172/impp.2004.6.2.344

Holtz, G., Alkemade, F., de Haan, F., Köhler, J., Trutnevyte, E., Luthe, T., Halbe, J., Papachristos, G., Chappin, E., Kwakkel, J., Ruutu, S., 2015. Prospects of modelling societal transitions: Position paper of an emerging community. Environ. Innov. Soc. Transit. 17, 41–58. https://doi.org/10.1016/j.eist.2015.05.006

Howard, P., Sylvan, D., 2015. Expert consensus on the economics of climate change. Institute for Policy Integrity, New York.

Hughes, N., Strachan, N., Gross, R., 2013. The structure of uncertainty in future low carbon pathways. Energy Policy 52, 45–54. https://doi.org/10.1016/j.enpol.2012.04.028

Hughes, T.P., 1987. The evolution of large technological systems, in: Bijker, W.E., Hughes, T.P., Pinch, T. (Eds.), The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology. MIT Press, Cambridge, pp. 51–82.

Ingram, J., Maye, D., Kirwan, J., Curry, N., Kubinakova, K., 2015. Interactions between niche and regime: an analysis of learning and innovation networks for sustainable agriculture across Europe. J. Agric. Educ. Ext. 21, 55–71. https://doi.org/10.1080/1389224X.2014.991114

International Energy Agency, 2018. Global energy and CO2 status report 2017. OECD/IEA, Paris.

International Energy Agency, 2017. Energy technology perspectives 2017: Catalysing energy technology transformations. OECD/IEA, Paris.

IPCC, 2014a. Climate change 2014: Mitigation of climate change: Working Group III contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

IPCC, 2014c. Climate change 2014: Synthesis report. Intergovernmental Panel on Climate Change, Geneva, Switzerland.

IPCC, 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jaccard, M., 2016. Want an effective climate policy? Heed the evidence [WWW Document]. Policy Options. URL http://policyoptions.irpp.org/magazines/february-2016/want-an-effective-climatepolicy-heed-the-evidence/ (accessed 4.28.17).

Jacobson, M.Z., Delucchi, M.A., 2009. A path to sustainable energy by 2030. Sci. Am. 301, 58–65.

Jacobson, M.Z., Delucchi, M.A., Bauer, Z.A.F., Goodman, S.C., Chapman, W.E., Cameron, M.A., Bozonnat, C., Chobadi, L., Clonts, H.A., Enevoldsen, P., Erwin, J.R., Fobi, S.N., Goldstrom, O.K., Hennessy, E.M., Liu, J., Lo, J., Meyer, C.B., Morris, S.B., Moy, K.R., O'Neill, P.L., Petkov, I., Redfern, S., Schucker, R., Sontag, M.A., Wang, J., Weiner, E., Yachanin, A.S., 2017. 100% clean and renewable wind, water, and sunlight all-sector energy roadmaps for 139 countries of the world. Joule 1, 108–121. https://doi.org/10.1016/j.joule.2017.07.005

Jacobson, M.Z., Delucchi, M.A., Bazouin, G., Bauer, Z.A.F., Heavey, C.C., Fisher, E., Morris, S.B., Piekutowski, D.J.Y., Vencill, T.A., Yeskoo, T.W., 2015. 100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for the 50 United States. Energy Env. Sci 8, 2093–2117. https://doi.org/10.1039/C5EE01283J

Jacobsson, S., Lauber, V., 2006. The politics and policy of energy system transformation—explaining the German diffusion of renewable energy technology. Energy Policy 34, 256–276. https://doi.org/10.1016/j.enpol.2004.08.029

Johnstone, P., Kivimaa, P., 2018. Multiple dimensions of disruption, energy transitions and industrial policy. Energy Res. Soc. Sci. 37, 260–265. https://doi.org/10.1016/j.erss.2017.10.027

Kalvapalle, R., 2018. 7 in 10 Ontarians think carbon taxes are just a tax grab: Ipsos poll [WWW Document]. Glob. News. URL https://globalnews.ca/news/4204847/ontario-carbon-tax-election-poll/ (accessed 5.16.18).

Keary, M., 2016. The New Prometheans: Technological Optimism in Climate Change Mitigation Modelling. Environ. Values 25, 7–28. https://doi.org/10.3197/096327115X14497392134801

Kemp, R., Loorbach, D., Rotmans, J., 2007. Transition management as a model for managing processes of co-evolution towards sustainable development. Int. J. Sustain. Dev. World Ecol. 14, 78–91. https://doi.org/10.1080/13504500709469709

Kemp, R., Rip, A., Schot, J.W., 2001. Constructing transition paths through the management of niches, in: Garud, R., Karnoe, P. (Eds.), Path Dependence and Creation. Lawrence Erlbaum, Mahwa (N.J.) and London, pp. 269–299.

Kemp, R., Schot, J., Hoogma, R., 1998. Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. Technol. Anal. Strateg. Manag. 10, 175–198.

Kern, F., 2012. The discursive politics of governing transitions towards sustainability: the UK Carbon Trust. Int. J. Sustain. Dev. 15, 90–106.

Kern, F., Rogge, K.S., 2018. Harnessing theories of the policy process for analysing the politics of sustainability transitions: A critical survey. Environ. Innov. Soc. Transit. 27, 102–117. https://doi.org/10.1016/j.eist.2017.11.001

Kern, F., Rogge, K.S., 2016. The pace of governed energy transitions: Agency, international dynamics and the global Paris agreement accelerating decarbonisation processes? Energy Res. Soc. Sci. 22, 13–17. https://doi.org/10.1016/j.erss.2016.08.016

Kivimaa, P., Hildén, M., Huitema, D., Jordan, A., Newig, J., 2017. Experiments in climate governance – A systematic review of research on energy and built environment transitions. J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2017.01.027

Kivimaa, P., Kern, F., 2016. Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. Res. Policy 45, 205–217. https://doi.org/10.1016/j.respol.2015.09.008

Klitkou, A., Bolwig, S., Hansen, T., Wessberg, N., 2015. The role of lock-in mechanisms in transition processes: The case of energy for road transport. Environ. Innov. Soc. Transit. 16, 22–37. https://doi.org/10.1016/j.eist.2015.07.005

Köhler, J., Geels, F.W., Kern, F., Markard, J., Wieczorek, A., Alkemade, F., Avelino, F., Bergek, A., Boons, F., Fünfschilling, L., Hess, D., Holtz, G., Hyysalo, S., Jenkins, K., Kivimaa, P., Martiskainen, M., McMeekin, A., Mühlemeier, M.S., Nykvist, B., Onsongo, E., Pel, B., Raven, R., Rohracher, H., Sandén, B., Schot, J., Sovacool, B., Turnheim, B., Welch, D., Wells, P., 2019. An agenda for sustainability transitions research: State of the art and future directions. Environ. Innov. Soc. Transit. https://doi.org/10.1016/j.eist.2019.01.004

Konrad, K., Truffer, B., Voß, J.-P., 2008. Multi-regime dynamics in the analysis of sectoral transformation potentials: evidence from German utility sectors. J. Clean. Prod. 16, 1190–1202. https://doi.org/10.1016/j.jclepro.2007.08.014

Lakoff, G., Johnson, M., 1980. Metaphors we live by. University of Chicago Press.

Layzell, D.B., Beaumier, L., 2018. Change Ahead: A Case for Independent Expert Analysis and Advice in Support of Climate Policy Making in Canada. Canadian Energy Systems Analysis Research Initiative, Calgary.

Leipprand, A., Flachsland, C., 2018. Regime destabilization in energy transitions: The German debate on the future of coal. Energy Res. Soc. Sci. 40, 190–204. https://doi.org/10.1016/j.erss.2018.02.004

Levin, K., Cashore, B., Bernstein, S., Auld, G., 2012. Overcoming the tragedy of super wicked problems: constraining our future selves to ameliorate global climate change. Policy Sci. 45, 123–152. https://doi.org/10.1007/s11077-012-9151-0

Li, F.G.N., Strachan, N., 2017. Modelling energy transitions for climate targets under landscape and actor inertia. Environ. Innov. Soc. Transit. 24, 106–129. https://doi.org/10.1016/j.eist.2016.08.002

Li, F.G.N., Trutnevyte, E., Strachan, N., 2015. A review of socio-technical energy transition (STET) models. Technol. Forecast. Soc. Change 100, 290–305. https://doi.org/10.1016/j.techfore.2015.07.017

Lilliestam, J., Hanger, S., 2016. Shades of green: Centralisation, decentralisation and controversy among European renewable electricity visions. Energy Res. Soc. Sci. 17, 20–29. https://doi.org/10.1016/j.erss.2016.03.011

Lockwood, M., Kuzemko, C., Mitchell, C., Hoggett, R., 2017. Historical institutionalism and the politics of sustainable energy transitions: A research agenda. Environ. Plan. C Polit. Space 35, 312–333. https://doi.org/10.1177/0263774X16660561

Loorbach, D., Rotmans, J., 2010. The practice of transition management: Examples and lessons from four distinct cases. Futures 42, 237–246. https://doi.org/10.1016/j.futures.2009.11.009

Lundvall, B.-Å., 1992. National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning. Pinter Publishers.

Mace, M., 2017. Claire Perry: Clean Growth Strategy will set “decarbonisation pathway” across UK economy [WWW Document]. edie.net. URL https://www.edie.net/news/11/Claire-Perry--Clean-Growth-Strategy-will-set--decarbonisation-pathway--across-the-UK-economy/ (accessed 4.4.18).

Mahoney, J., 2000. Path dependence in historical sociology. Theory Soc. 29, 507–548.

Mallett, A., Jegen, M., Philion, X.D., Reiber, R., Rosenbloom, D., 2018. Smart grid framing through coverage in the Canadian media: Technologies coupled with experiences. Renew. Sustain. Energy Rev. 82, 1952–1960. https://doi.org/10.1016/j.rser.2017.06.013

Markard, J., 2018. The next phase of the energy transition and its implications for research and policy. Nat. Energy. https://doi.org/10.1038/s41560-018-0171-7

Markard, J., Hekkert, M., Jacobsson, S., 2015. The technological innovation systems framework: Response to six criticisms. Environ. Innov. Soc. Transit. 16, 76–86. https://doi.org/10.1016/j.eist.2015.07.006

Markard, J., Raven, R., Truffer, B., 2012. Sustainability transitions: an emerging field of research and its prospects. Res. Policy 41, 955–967. https://doi.org/10.1016/j.respol.2012.02.013

Markard, J., Suter, M., Ingold, K., 2016. Socio-technical transitions and policy change – Advocacy coalitions in Swiss energy policy. Environ. Innov. Soc. Transit. 18, 215–237. https://doi.org/10.1016/j.eist.2015.05.003

Markard, J., Truffer, B., 2008. Technological innovation systems and the multi-level perspective: Towards an integrated framework. Res. Policy 37, 596–615. https://doi.org/10.1016/j.respol.2008.01.004

Markusson, N., Shackley, S., Evar, B., 2012. The Social Dynamics of Carbon Capture and Storage: Understanding CCS Representations, Governance and Innovation. Routledge.

Martin, C.J., 2016. The sharing economy: A pathway to sustainability or a nightmarish form of neoliberal capitalism? Ecol. Econ. 121, 149–159. https://doi.org/10.1016/j.ecolecon.2015.11.027

Martínez Arranz, A., 2017. Lessons from the past for sustainability transitions? A meta-analysis of socio-technical studies. Glob. Environ. Change 44, 125–143. https://doi.org/10.1016/j.gloenvcha.2017.03.007

Marzeion, B., Cogley, J.G., Richter, K., Parkes, D., 2014. Attribution of global glacier mass loss to anthropogenic and natural causes. Science 345, 919–921. https://doi.org/10.1126/science.1254702

McDowall, W., 2014. Exploring possible transition pathways for hydrogen energy: A hybrid approach using socio-technical scenarios and energy system modelling. Futures 63, 1–14. https://doi.org/10.1016/j.futures.2014.07.004

McKinsey & Company, 2009. Pathways to a low-carbon economy: Version 2 of the global greenhouse gas abatement cost curve.

Meadowcroft, J., 2011. Engaging with the politics of sustainability transitions. Environ. Innov. Soc. Transit. 1, 70–75. https://doi.org/10.1016/j.eist.2011.02.003

Meadowcroft, J., 2009. What about the politics? Sustainable development, transition management, and long term energy transitions. Policy Sci. 42, 323–340. https://doi.org/10.1007/s11077-009-9097-z

Meadowcroft, J., 2007. Who is in Charge here? Governance for Sustainable Development in a Complex World*. J. Environ. Policy Plan. 9, 299–314. https://doi.org/10.1080/15239080701631544

Meadowcroft, J., 2000. Sustainable development: a new (ish) idea for a new century? Polit. Stud. 48, 370–387.

Meadowcroft, J., Fiorino, D., 2017. Conceptual innovation in environmental policy. The MIT Press.

Meckling, J., Nahm, J., 2019. The politics of technology bans: Industrial policy competition and green goals for the auto industry. Energy Policy 126, 470–479. https://doi.org/10.1016/j.enpol.2018.11.031
Mendelsohn, R., Dinar, A., Williams, L., 2006. The distributional impact of climate change on rich and poor countries. Environ. Dev. Econ. 11, 159–178. https://doi.org/10.1017/S1355770X05002755
Miller, C.A., O'Leary, J., Graffy, E., Stechel, E.B., Dirks, G., 2015. Narrative futures and the governance of energy transitions. Futures 70, 65–74. https://doi.org/10.1016/j.futures.2014.12.001
Ministère de la Transition écologique et solidaire, 2017. National low-carbon strategy. Government of the French Republic, Paris.
Moezzi, M., Janda, K.B., Rotmann, S., 2017. Using stories, narratives, and storytelling in energy and climate change research. Energy Res. Soc. Sci., Narratives and Storytelling in Energy and Climate Change Research 31, 1–10. https://doi.org/10.1016/j.erss.2017.06.034
Mordue, G., 2017. Electricity prices and industrial competitiveness: A case study of final assembly automobile manufacturing in the United States and Canada. Energy Policy 111, 32–40. https://doi.org/10.1016/j.enpol.2017.09.008
Morone, P., Falcone, P.M., Lopolito, A., 2019. How to promote a new and sustainable food consumption model: A fuzzy cognitive map study. J. Clean. Prod. 208, 563–574. https://doi.org/10.1016/j.jclepro.2018.10.075
Morrison, G.M., Yeh, S., Eggert, A.R., Yang, C., Nelson, J.H., Greenblatt, J.B., Isaac, R., Jacobson, M.Z., Johnston, J., Kammen, D.M., Mileva, A., Moore, J., Roland-Holst, D., Wei, M., Weyant, J.P., Williams, J.H., Williams, R., Zapata, C.B., 2015. Comparison of low-carbon pathways for California. Clim. Change 131, 545–557. https://doi.org/10.1007/s10584-015-1403-5
Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., van Vuuren, D.P., Carter, T.R., Emori, S., Kainuma, M., Kram, T., Meehl, G.A., Mitchell, J.F.B., Nakićenović, N., Riahi, K., Smith, S.J., Stouffer, R.J., Thomson, A.M., Weyant, J.P., Wilbanks, T.J., 2010. The next generation of scenarios for climate change research and assessment. Nature 463, 747–757. https://doi.org/10.1038/nature08823
Mühlhäusler, P., Peace, A., 2006. Environmental Discourses. Annu. Rev. Anthropol. 35, 457–479. https://doi.org/10.1146/annurev.anthro.35.081705.123203
Nakićenović, N., 2000. Greenhouse gas emissions scenarios. Technol. Forecast. Soc. Change 65, 149–166.
NASA Global Climate Change, 2018. Carbon dioxide [WWW Document]. Clim. Change Vital Signs Planet. URL https://climate.nasa.gov/vital-signs/carbon-dioxide (accessed 3.27.18).
Negro, S.O., Alkemade, F., Hekkert, M.P., 2012. Why does renewable energy diffuse so slowly? A review of innovation system problems. Renew. Sustain. Energy Rev. 16, 3836–3846. https://doi.org/10.1016/j.rser.2012.03.043
Negro, S.O., Hekkert, M.P., Smits, R.E., 2007. Explaining the failure of the Dutch innovation system for biomass digestion—A functional analysis. Energy Policy 35, 925–938. https://doi.org/10.1016/j.enpol.2006.01.027
Nelson, R.R., 1994. The Co-evolution of Technology, Industrial Structure, and Supporting Institutions 3, 47–63.

Nelson, R.R., Winter, S.G., 1982. An evolutionary theory of economic change. The Belknap Press, Cambridge, Mass.
Nelson, R.R., Winter, S.G., 1977. In search of useful theory of innovation. Res. Policy 6, 36–76. https://doi.org/10.1016/0048-7333(77)90029-4
North, D.C., 1990. Institutions, institutional change and economic performance. Cambridge University Press, Cambridge.
O'Brien, K., 2018. Is the 1.5°C target possible? Exploring the three spheres of transformation. Curr. Opin. Environ. Sustain. 31, 153–160. https://doi.org/10.1016/j.cosust.2018.04.010
O'Neill, B.C., Kriegler, E., Ebi, K.L., Kemp-Benedict, E., Riahi, K., Rothman, D.S., van Ruijven, B.J., van Vuuren, D.P., Birkmann, J., Kok, K., Levy, M., Solecki, W., 2017. The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. Glob. Environ. Change 42, 169–180. https://doi.org/10.1016/j.gloenvcha.2015.01.004
O'Neill, B.C., Kriegler, E., Riahi, K., Ebi, K.L., Hallegatte, S., Carter, T.R., Mathur, R., van Vuuren, D.P., 2014. A new scenario framework for climate change research: the concept of shared socioeconomic pathways. Clim. Change 122, 387–400. https://doi.org/10.1007/s10584-013-0905-2
Ontario Ministry of Energy, 2016. Planning Ontario's energy future: a discussion guide to start the conversation. Queen's Printer for Ontario, Toronto.
Ontario Ministry of Energy, 2015. The end of coal: An Ontario primer on modernizing electricity supply. Queen's Printer for Ontario, Toronto.
Pahl, S., Sheppard, S., Boomsma, C., Groves, C., 2014. Perceptions of time in relation to climate change. Wiley Interdiscip. Rev. Clim. Change 5, 375–388. https://doi.org/10.1002/wcc.272
Papachristos, G., 2014. Towards multi-system sociotechnical transitions: why simulate. Technol. Anal. Strateg. Manag. 26, 1037–1055. https://doi.org/10.1080/09537325.2014.944148
Papachristos, G., Sofianos, A., Adamides, E., 2013. System interactions in socio-technical transitions: Extending the multi-level perspective. Environ. Innov. Soc. Transit. 7, 53–69. https://doi.org/10.1016/j.eist.2013.03.002
Petroff, A., 2017. These countries want to ban gas and diesel cars [WWW Document]. CNN Money. URL http://money.cnn.com/2017/09/11/autos/countries-banning-diesel-gas-cars/index.html (accessed 11.17.17).
Pierson, P., 2000. Increasing returns, path dependence, and the study of politics. Am. Polit. Sci. Rev. 251–267.
Polasky, S., Carpenter, S.R., Folke, C., Keeler, B., 2011. Decision-making under great uncertainty: environmental management in an era of global change. Trends Ecol. Evol. 26, 398–404. https://doi.org/10.1016/j.tree.2011.04.007
Pope, C.G., 2018. China wants to dominate the world's green energy markets – here's why [WWW Document]. The Conversation. URL http://theconversation.com/china-wants-to-dominate-the-worlds-green-energy-markets-heres-why-89708 (accessed 5.16.18).
Raupach, M.R., Canadell, J.G., 2010. Carbon and the Anthropocene. Curr. Opin. Environ. Sustain. 2, 210–218. https://doi.org/10.1016/j.cosust.2010.04.003
Raven, R., 2007. Co-evolution of waste and electricity regimes: Multi-regime dynamics in the Netherlands (1969–2003). Energy Policy 35, 2197–2208. https://doi.org/10.1016/j.enpol.2006.07.005

Raven, R., Kern, F., Smith, A., Jacobsson, S., Verhees, B., 2016. The politics of innovation spaces for low-carbon energy: Introduction to the special issue. Environ. Innov. Soc. Transit. 18, 101–110. https://doi.org/10.1016/j.eist.2015.06.008

Raven, R., Verbong, G., 2007. Multi-regime interactions in the Dutch energy sector: the case of combined heat and power technologies in the Netherlands 1970–2000. Technol. Anal. Strateg. Manag. 19, 491–507. https://doi.org/10.1080/09537320701403441

Raven, R.P.J.M., 2005. Strategic niche management for biomass: a comparative study on the experimental introduction of bioenergy technologies in the Netherlands and Denmark. Technische Universiteit Eindhoven, Eindhoven.

REN21, 2017. Renewables 2017: Global status report. Renewable Energy Policy Network for the 21st Century, Paris.

Riahi, K., Dentener, F., Gielen, D., Grubler, A., Jewell, J., Klimont, Z., Krey, V., McCollum, D., Pachauri, S., Rao, S., Ruijven, B. van, Vuuren, D.P. van, Wilson, C., Isaac, M., Jaccard, M., Kobayashi, S., Kolp, P., Larson, E.D., Nagai, Y., Purohit, P., Schers, J., ?rge-Vorsatz, D., Dingenen, R. van, Vliet, O. van, Morgan, G., 2012. Energy pathways for sustainable development, in: Global Energy Assessment: Toward a Sustainable Future. Cambridge University Press, Cambridge, pp. 1205–1305.

Riahi, K., van Vuuren, D.P., Kriegler, E., Edmonds, J., O'Neill, B.C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J.C., Kc, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., Ebi, K., Hasegawa, T., Havlik, P., Humpenöder, F., Da Silva, L.A., Smith, S., Stehfest, E., Bosetti, V., Eom, J., Gernaat, D., Masui, T., Rogelj, J., Strefler, J., Drouet, L., Krey, V., Luderer, G., Harmsen, M., Takahashi, K., Baumstark, L., Doelman, J.C., Kainuma, M., Klimont, Z., Marangoni, G., Lotze-Campen, H., Obersteiner, M., Tabeau, A., Tavoni, M., 2017. The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Glob. Environ. Change 42, 153–168. https://doi.org/10.1016/j.gloenvcha.2016.05.009

Roberts, C., Geels, F.W., Lockwood, M., Newell, P., Schmitz, H., Turnheim, B., Jordan, A., 2018. The politics of accelerating low-carbon transitions: Towards a new research agenda. Energy Res. Soc. Sci. 44, 304–311. https://doi.org/10.1016/j.erss.2018.06.001

Roberts, J.C.D., 2017. Discursive destabilisation of socio-technical regimes: Negative storylines and the discursive vulnerability of historical American railroads. Energy Res. Soc. Sci. 31, 86–99. https://doi.org/10.1016/j.erss.2017.05.031

Rogelj, J., Luderer, G., Pietzcker, R.C., Kriegler, E., Schaeffer, M., Krey, V., Riahi, K., 2015. Energy system transformations for limiting end-of-century warming to below 1.5 °C. Nat. Clim. Change 5, 519–527. https://doi.org/10.1038/nclimate2572

Rogers, E.M., 1983. Diffusion of innovations, 3rd ed. ed. Free Press ; Collier Macmillan, New York : London.

Rogge, K.S., Pfluger, B., Geels, F.W., 2018. Transformative policy mixes in socio-technical scenarios: The case of the low-carbon transition of the German electricity system (2010–2050). Technol. Forecast. Soc. Change. https://doi.org/10.1016/j.techfore.2018.04.002

Rosenbloom, D., 2018. Framing low-carbon pathways: A discursive analysis of contending storylines surrounding the phase-out of coal-fired power in Ontario. Environ. Innov. Soc. Transit. 27, 129–145. https://doi.org/10.1016/j.eist.2017.11.003

Rosenbloom, D., 2017. Pathways: an emerging concept for the theory and governance of low-carbon transitions. Glob. Environ. Change 43, 37–50. https://doi.org/10.1016/j.gloenvcha.2016.12.011
Rosenbloom, D., Berton, H., Meadowcroft, J., 2016. Framing the sun: a discursive approach to understanding multi-dimensional interactions within socio-technical transitions through the case of solar electricity in Ontario, Canada. Res. Policy 45, 1275–1290. https://doi.org/10.1016/j.respol.2016.03.012
Rosenbloom, D., Haley, B., Meadowcroft, J., 2018a. Critical choices and the politics of decarbonization pathways: exploring branching points surrounding low-carbon transitions in Canadian electricity systems. Energy Res. Soc. Sci. 37, 22–36. https://doi.org/10.1016/j.erss.2017.09.022
Rosenbloom, D., Meadowcroft, J., 2014. The journey towards decarbonization: exploring socio-technical transitions in the electricity sector in the province of Ontario (1885–2013) and potential low-carbon pathways. Energy Policy 65, 670–679. https://doi.org/10.1016/j.enpol.2013.09.039
Rosenbloom, D., Meadowcroft, J., Cashore, B., 2019. Stability and climate policy? Harnessing insights on path dependence, policy feedback, and transition pathways. Energy Res. Soc. Sci. 50, 168–178. https://doi.org/10.1016/j.erss.2018.12.009
Rosenbloom, D., Meadowcroft, J., Sheppard, S., Burch, S., Williams, S., 2018b. Transition experiments: Opening up low-carbon transition pathways for Canada through innovation and learning. Can. Public Policy 44, 368–383. https://doi.org/10.3138/cpp.2018-020
Rotmans, J., Kemp, R., Van Asselt, M., 2001. More evolution than revolution: transition management in public policy. foresight 3, 15–31.
Rotmans, J., Loorbach, D., 2009. Complexity and Transition Management. J. Ind. Ecol. 13, 184–196. https://doi.org/10.1111/j.1530-9290.2009.00116.x
Schmidt, T.S., Sewerin, S., 2017. Technology as a driver of climate and energy politics. Nat. Energy. https://doi.org/10.1038/nenergy.2017.84
Schmidt, V.A., 2010. Taking ideas and discourse seriously: explaining change through discursive institutionalism as the fourth 'new institutionalism.' Eur. Polit. Sci. Rev. 2, 1. https://doi.org/10.1017/S175577390999021X
Schmidt, V.A., 2008. Discursive Institutionalism: The Explanatory Power of Ideas and Discourse. Annu. Rev. Polit. Sci. 11, 303–326. https://doi.org/10.1146/annurev.polisci.11.060606.135342
Schön, D.A., 1993. Generative metaphor: A perspective on problem-setting in social policy, in: Ortony, A. (Ed.), Metaphor and Thought. Cambridge University Press, Cambridge, United Kingdom, pp. 137–163.
Schot, J., Geels, F.W., 2008. Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. Technol. Anal. Strateg. Manag. 20, 537–554. https://doi.org/10.1080/09537320802292651
Sengers, F., Wieczorek, A.J., Raven, R., 2016. Experimenting for sustainability transitions: A systematic literature review. Technol. Forecast. Soc. Change. https://doi.org/10.1016/j.techfore.2016.08.031
Shaw, A., Sheppard, S., Burch, S., Flanders, D., Wiek, A., Carmichael, J., Robinson, J., Cohen, S., 2009. Making local futures tangible—Synthesizing, downscaling, and visualizing climate

change scenarios for participatory capacity building. Glob. Environ. Change 19, 447–463. https://doi.org/10.1016/j.gloenvcha.2009.04.002
Shell, 2018. Sky: meeting the goals of the Paris Agreement, Shell scenarios. Shell International.
Sheller, M., Urry, J., 2002. The City and the Car. Int. J. Urban Reg. Res. 24, 737–757. https://doi.org/10.1111/1468-2427.00276
Sheppard, S.R.J., Shaw, A., Flanders, D., Burch, S., Wiek, A., Carmichael, J., Robinson, J., Cohen, S., 2011. Future visioning of local climate change: A framework for community engagement and planning with scenarios and visualisation. Futures 43, 400–412. https://doi.org/10.1016/j.futures.2011.01.009
Shove, E., Walker, G., 2007. CAUTION! Transitions ahead: politics, practice, and sustainable transition management. Environ. Plan. A 39, 763–770. https://doi.org/10.1068/a39310
Shove, E., Walker, G., Brown, S., 2014. Material culture, room temperature and the social organisation of thermal energy. J. Mater. Cult. 1359183514525084. https://doi.org/10.1177/1359183514525084
Silva, A., Stocker, L., 2018. What is a transition? Exploring visual and textual definitions among sustainability transition networks. Glob. Environ. Change 50, 60–74. https://doi.org/10.1016/j.gloenvcha.2018.02.003
Smil, V., 2016. Examining energy transitions: A dozen insights based on performance. Energy Res. Soc. Sci. 22, 194–197. https://doi.org/10.1016/j.erss.2016.08.017
Smink, M.M., Hekkert, M.P., Negro, S.O., 2015. Keeping sustainable innovation on a leash? Exploring incumbents' institutional strategies. Bus. Strategy Environ. 24, 86–101. https://doi.org/10.1002/bse.1808
Smith, A., 2007. Translating sustainabilities between green niches and socio-technical regimes. Technol. Anal. Strateg. Manag. 19, 427–450. https://doi.org/10.1080/09537320701403334
Smith, A., Kern, F., 2009. The transitions storyline in Dutch environmental policy. Environ. Polit. 18, 78–98. https://doi.org/10.1080/09644010802624835
Smith, A., Kern, F., Raven, R., Verhees, B., 2014. Spaces for sustainable innovation: Solar photovoltaic electricity in the UK. Technol. Forecast. Soc. Change 81, 115–130. https://doi.org/10.1016/j.techfore.2013.02.001
Smith, A., Raven, R., 2012. What is protective space? Reconsidering niches in transitions to sustainability. Res. Policy 41, 1025–1036. https://doi.org/10.1016/j.respol.2011.12.012
Smith, A., Stirling, A., Berkhout, F., 2005. The governance of sustainable socio-technical transitions. Res. Policy 34, 1491–1510. https://doi.org/10.1016/j.respol.2005.07.005
Smith, A., Voß, J.-P., Grin, J., 2010. Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges. Res. Policy 39, 435–448. https://doi.org/10.1016/j.respol.2010.01.023
Sovacool, B.K., 2016. How long will it take? Conceptualizing the temporal dynamics of energy transitions. Energy Res. Soc. Sci. 13, 202–215. https://doi.org/10.1016/j.erss.2015.12.020
Sovacool, B.K., Geels, F.W., 2016. Further reflections on the temporality of energy transitions: A response to critics. Energy Res. Soc. Sci. 22, 232–237. https://doi.org/10.1016/j.erss.2016.08.013
Sovacool, B.K., Hess, D.J., 2017. Ordering theories: Typologies and conceptual frameworks for sociotechnical change. Soc. Stud. Sci. 47, 703–750. https://doi.org/10.1177/0306312717709363

Späth, P., Rohracher, H., 2010. ‘Energy regions’: The transformative power of regional discourses on socio-technical futures. Res. Policy 39, 449–458. https://doi.org/10.1016/j.respol.2010.01.017

Steffen, W., Richardson, K., Rockstrom, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sorlin, S., 2015. Planetary boundaries: Guiding human development on a changing planet. Science 347, 1259855–1259855. https://doi.org/10.1126/science.1259855

Stephens, J.C., Wilson, E.J., Peterson, T.R., 2008. Socio-Political Evaluation of Energy Deployment (SPEED): An integrated research framework analyzing energy technology deployment. Technol. Forecast. Soc. Change 75, 1224–1246. https://doi.org/10.1016/j.techfore.2007.12.003

Stern, N., 2007. The economics of climate change: The Stern review. Cambridge University Press, Cambridge.

Stiglitz, J.E., Stern, N., 2017. Report of the high-level commission on carbon prices. Carbon pricing leadership coalition.

Stokes, L.C., 2013. The politics of renewable energy policies: The case of feed-in tariffs in Ontario, Canada. Energy Policy 56, 490–500. https://doi.org/10.1016/j.enpol.2013.01.009

Stone, D., 2001. Policy Paradox: The Art of Political Decision Making, 3rd edition. ed. W. W. Norton & Company, New York.

Swart, R.., Raskin, P., Robinson, J., 2004. The problem of the future: sustainability science and scenario analysis. Glob. Environ. Change 14, 137–146. https://doi.org/10.1016/j.gloenvcha.2003.10.002

Teschner, N., Paavola, J., 2013. Discourses of Abundance: Transitions in Israel’s Energy Regime. J. Environ. Policy Plan. 15, 447–466. https://doi.org/10.1080/1523908X.2013.776954

The Canadian Press, 2018. Pro-pipeline rally draws 1,000 attendees in Alberta town of about 6,600 [WWW Document]. CBC News. URL https://www.cbc.ca/news/canada/calgary/rocky-mountain-house-protest-1.4961616 (accessed 1.3.19).

The Generation Energy Council, 2018. Canada’s energy transition: Getting to our energy future, together. Natural Resources Canada, Ottawa.

The Solution Project, 2016. 100% Renewable Energy [WWW Document]. Solut. Proj. URL http://thesolutionsproject.org/ (accessed 8.9.16).

Tol, R.S.J., Downing, T.E., Kuik, O.J., Smith, J.B., 2004. Distributional aspects of climate change impacts. Glob. Environ. Change, The Benefits of Climate Policy 14, 259–272. https://doi.org/10.1016/j.gloenvcha.2004.04.007

Turnheim, B., Berkhout, F., Geels, F.W., Hof, A., McMeekin, A., Nykvist, B., van Vuuren, D.P., 2015. Evaluating sustainability transitions pathways: Bridging analytical approaches to address governance challenges. Glob. Environ. Change 35, 239–253. https://doi.org/10.1016/j.gloenvcha.2015.08.010

Turnheim, B., Geels, F.W., 2012. Regime destabilisation as the flipside of energy transitions: Lessons from the history of the British coal industry (1913–1997). Energy Policy 50, 35–49. https://doi.org/10.1016/j.enpol.2012.04.060

Tvinnereim, E., Mehling, M., 2018. Carbon pricing and deep decarbonisation. Energy Policy 121, 185–189. https://doi.org/10.1016/j.enpol.2018.06.020

UK Government, 2017. The clean growth strategy: leading the way to a low carbon future. Her Majesty's Government, London.
UK Government, 2013. 2050 pathways [WWW Document]. URL https://www.gov.uk/guidance/2050-pathways-analysis (accessed 2.23.16).
UN News, 2016a. In China, Ban highlights country's leadership on sustainable development, climate change [WWW Document]. U. N. URL https://news.un.org/en/story/2016/07/533972-china-ban-highlights-countrys-leadership-sustainable-development-climate-change (accessed 4.4.18).
UN News, 2016b. UN urges action on sustainable development to create pathways for global "transformation" [WWW Document]. U. N. URL https://news.un.org/en/story/2016/04/527322-un-urges-action-sustainable-development-create-pathways-global-transformation (accessed 4.4.18).
United Nations Framework Convention on Climate Change, 2015. Adoption of the Paris Agreement, 21st Conference of the Parties. United Nations, Paris.
Unruh, G.C., 2000. Understanding carbon lock-in. Energy Policy 28, 817–830.
van Sluisveld, M.A.E., Hof, A.F., Carrara, S., Geels, F.W., Nilsson, M., Rogge, K., Turnheim, B., van Vuuren, D.P., 2018. Aligning integrated assessment modelling with socio-technical transition insights: An application to low-carbon energy scenario analysis in Europe. Technol. Forecast. Soc. Change. https://doi.org/10.1016/j.techfore.2017.10.024
van Vuuren, D.P., Deetman, S., van Vliet, J., van den Berg, M., van Ruijven, B.J., Koelbl, B., 2013. The role of negative CO2 emissions for reaching 2 °C—insights from integrated assessment modelling. Clim. Change 118, 15–27. https://doi.org/10.1007/s10584-012-0680-5
van Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J.-F., Masui, T., Meinshausen, M., Nakićenović, N., Smith, S.J., Rose, S.K., 2011. The representative concentration pathways: an overview. Clim. Change 109, 5–31. https://doi.org/10.1007/s10584-011-0148-z
van Vuuren, D.P., Riahi, K., Moss, R., Edmonds, J., Thomson, A., Nakicenovic, N., Kram, T., Berkhout, F., Swart, R., Janetos, A., Rose, S.K., Arnell, N., 2012. A proposal for a new scenario framework to support research and assessment in different climate research communities. Glob. Environ. Change 22, 21–35. https://doi.org/10.1016/j.gloenvcha.2011.08.002
Vaughan, A., 2017. Carmakers say fossil-fuel vehicle ban will dent industry and stall sales. The Guardian.
Verhees, B., Raven, R., Kern, F., Smith, A., 2015. The role of policy in shielding, nurturing and enabling offshore wind in The Netherlands (1973–2013). Renew. Sustain. Energy Rev. 47, 816–829. https://doi.org/10.1016/j.rser.2015.02.036
Walker, G., Shove, E., Brown, S., 2014. How does air conditioning become 'needed'? A case study of routes, rationales and dynamics. Energy Res. Soc. Sci. 4, 1–9. https://doi.org/10.1016/j.erss.2014.08.002
Wieczorek, A.J., Hekkert, M.P., 2012. Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. Sci. Public Policy 39, 74–87. https://doi.org/10.1093/scipol/scr008
Wilson, C., Tyfield, D., 2018. Critical perspectives on disruptive innovation and energy transformation. Energy Res. Soc. Sci. 37, 211–215. https://doi.org/10.1016/j.erss.2017.10.032

Winskel, M., 2018. Beyond the disruption narrative: Varieties and ambiguities of energy system change. Energy Res. Soc. Sci. 37, 232–237. https://doi.org/10.1016/j.erss.2017.10.046
Wiseman, J., Edwards, T., Luckins, K., 2013. Post carbon pathways: A meta-analysis of 18 large-scale post carbon economy transition strategies. Environ. Innov. Soc. Transit. 8, 76–93. https://doi.org/10.1016/j.eist.2013.04.001
World Economic Forum, 2018. Fostering effective energy transition: A fact-based framework to support decision-making. WEF, Geneva.
Xiong, W., Lin, E., Ju, H., Xu, Y., 2007. Climate change and critical thresholds in China's food security. Clim. Change 81, 205–221. https://doi.org/10.1007/s10584-006-9123-5

Appendix 1

Paper 1: Pathways: an emerging concept for the theory and governance of low-carbon transitions

Global Environmental Change 43 (2017) 37–50

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

Pathways: An emerging concept for the theory and governance of low-carbon transitions

Daniel Rosenbloom

School of Public Policy and Administration, Carleton University, 1125 Colonel By Drive, Ottawa, K1S 5B6 ON, Canada

ARTICLE INFO

Article history:
Received 18 August 2016
Received in revised form 30 November 2016
Accepted 29 December 2016
Available online 5 February 2017

Keywords:
Pathways
Transitions
Transformations
Climate change mitigation
Decarbonization
Low-carbon

ABSTRACT

The concept of "pathways" has increasingly come to frame the challenge of transitioning to low-carbon societies. It also shows promise as a bridging concept, encouraging constructive dialogue among the diverse perspectives and constituencies evoking its use. However, its interpretations and attributes are rarely explicit and have yet to be subject to serious scrutiny. This raises important questions for both theory and governance as the way in which a problem is framed shapes how it is understood and addressed, structuring the possibilities considered and privileging certain responses. Therefore, this study explores the concept of pathways in the context of low-carbon transitions, exposing its conceptions, maturation, and implications. Based on a survey of the relevant climate change mitigation literature, this analysis uncovers three core conceptions of pathways in the context of low-carbon transitions: (1) biophysical, (2) techno-economic, and (3) socio-technical. Constituted by diverse perspectives and approaches, each of these three core conceptions emphasize different yet interconnected dimensions of the decarbonization challenge. This analysis also points to several key attributes and functions of the concept of pathways. Yet, while the concept may possess a variety of features that recommend its use as a critical problem frame for low-carbon transitions, it also raises issues that suggest a need for further reflexivity. If the concept is cast too strongly in terms of individual core conceptions, there may be a tendency to emphasize certain dynamics while paying somewhat less attention to others, inadvertently diminishing the complexity of the decarbonization challenge. Beyond this, there are other facets of the concept that have to date received more limited attention, including the implications of choices at critical junctures and the evolving character of social practices. So, there is room for the concept of pathways to engage more fully with the range of complexities embodied by low-carbon transitions.

1. Introduction

If the most severe impacts of climate change are to be avoided, societal systems such as transport and electric power will need to transition rapidly to low-carbon arrangements over the coming decades (IPCC, 2014). While rhetoric has to date outstripped concrete action, global leaders have increasingly recognized the necessity of a societal low-carbon transition (UNFCCC, 2015). Central to this transition is the project of deliberately moving from existing carbon-intensive arrangements toward low-carbon future states in 2030, 2050, and beyond. Within the policy and scholarly debate surrounding low-carbon transitions, the challenge of envisioning and moving toward desirable decarbonized futures has increasingly been framed in terms of *pathways* (Wise et al., 2014; Wiseman et al., 2013). Political leaders have, for instance, used pathways to recast development priorities in terms of long-term climate targets (G7, 2015; G8, 2008). Advanced industrial economies such as France and Britain have invoked pathways to animate post-carbon strategies (Wiseman et al., 2013). Among core intergovernmental bodies, pathways have been used to explore "time-dependent projections of atmospheric greenhouse gas (GHG) concentrations" (Moss et al., 2008, p. 4). Pathways have also received mounting attention across scholarly disciplines investigating the complexities of low-carbon transitions (Geels et al., 2016a; Morrison et al., 2015; Turnheim et al., 2015). Taken together, the concept of "pathways" has become increasingly tethered to the theory and practice of climate change mitigation and has been taken up by broad constituencies as a critical problem frame for low-carbon transitions.

Despite this preoccupation with pathways, its interpretations and attributes are rarely explicit and have yet to be subject to

E-mail address: daniel.rosenbloom@carleton.ca (D. Rosenbloom).

http://dx.doi.org/10.1016/j.gloenvcha.2016.12.011
0959-3780/

Table 1
Prominent actors contributing to the climate change mitigation debate.

Actors	
Intergovernmental and quasi-governmental organizations	Environmental think tanks
Group of 7/8 (G7/8)	World Resources Institute
International Energy Agency (IEA)	Stockholm Environment Institute
Intergovernmental Panel on Climate Change (IPCC)	Worldwatch Institute
Organisation for Economic Co-operation and Development (OECD)	Brookings Institution
United Nations Environment Programme (UNEP)	Center for Climate and Energy Solutions
United Nations Framework Convention on Climate Change (UNFCCC)	Chatham House
World Meteorological Organization (WMO)	Ecologic Institute

Organizations are adapted from Shaw and Nerlich (2015) and think tanks are drawn from McGann (2015).

serious scrutiny. This is particularly problematic for governance as concepts such as pathways shape the way we think about, structure, and act upon complex policy issues (Fischer and Forester, 1993; Stone, 2001). That is, concepts help to frame policy problems and may suggest particular courses of action while masking others (Schön, 1993). In this fashion, frames act as "a central organizing idea or storyline that provides meaning to an unfolding strip of events, weaving a connection among them" (Gamson and Modigliani, 1987, p. 143). Similarly, framing can be understood as a kind of world-making "from which an amorphous ill-defined, problematic situation can be made sense of and acted on" (Rein and Schön, 1993, p. 146). And, as reality is complex and multiple interpretations coexist simultaneously, actors can creatively leverage concepts in diverging ways to frame policy issues in such a fashion as to privilege particular solutions and interests (Rosenbloom et al., 2016; Shaw and Nerlich, 2015). Indeed, key policy concepts are subject to continual processes of reinterpretation and contestation (Collier et al., 2006; Meadowcroft and Fiorino, forthcoming), suggesting that there is an important role for self-reflection around their use in framing problems and orienting interventions.

Given the rising importance of the concept of pathways for framing low-carbon transitions, a careful interrogation of what this concept may suggest for contemplating and acting upon this challenge is merited. Thus, this study seeks to further scrutinize the concept of pathways in the context of low-carbon transitions, posing three central questions: (1) how is the concept variously understood across the diverse constituencies evoking its use; (2) what are the dynamics that mark the development of these different conceptions over time; and (3) where might this concept lead us in regards to the pursuit of low-carbon transitions? In addressing these questions, a core objective of this analysis is to provoke additional reflexivity and bridging opportunities among the constituencies deploying the concept of pathways. To this end, this study employs an exploratory literature survey to uncover and interrogate the contrasting conceptions of pathways that are emerging within the debate surrounding low-carbon transitions, shedding light on the multiple applications of the concept as well as the strands of research in which they are constituted. Findings reveal three core conceptions of pathways and suggest that while the concept is helping to bridge diverse perspectives (consider Davoudi et al., 2012; Paehlke, 2005 for a discussion of "bridging concepts"), it also raises important issues for the theory and governance of low-carbon transitions.

The argument in this paper proceeds in the following steps. The study begins by outlining the literature survey approach. Following this, the analysis presents three core conceptions of pathways. The paper concludes by underlining the attributes, implications, and functions of the concept as well as areas meriting further attention.

2. Approach: surveying the literature on pathways in the context of low-carbon transitions

In line with the aims of this study (i.e., to explore a multi-layered concept with emergent and contested properties), an exploratory literature survey was conducted to collect and analyze written sources contributing to the diverging conceptions of pathways in the context of low-carbon transitions. A date range of 1990 to 2016 was selected to coincide with the popularization of pathways in the work of the IPCC and its rising usage to this day. A mixed data collection strategy was employed to triangulate the identification and inclusion of relevant written sources. First, scholarly written sources were collected based on a keyword search[1] of peer-reviewed journal articles from relevant disciplines indexed in the SCOPUS database. After eliminating false positives, this step yielded an initial sample of 474 academic contributions. Second, written sources from the policy and practice domain were captured by selecting a set of prominent actors contributing to the climate change mitigation debate (see Table 1) and querying their online document libraries using the keywords "climate change" and "pathways". After removing false positives, this yielded an initial sample of 231 policy and practice documents. Third, the initial samples were further supplemented and crosschecked through reference tracking (examining the works cited by selected sources) and exposure to expert opinion (the comments offered during the 2016 International Sustainability Transitions Conference and the peer review process). Together, a total sample of over 725 written sources was amassed.

The analysis of written sources proceeded in an inductive, iterative, and interpretive fashion (consider Saini and Shlonsky, 2012 for an overview of interpretive survey approaches). Written sources were first scanned for pathways formulations and applications using search functions ("pathway"). This permitted the initial identification of emerging categories surrounding: (1) conceptions of pathways; (2) analytical approaches; and (3) emphases on particular dimensions of low-carbon transitions. From this, over 100 written sources with more substantive treatments of pathways were identified, subject to more in-depth analysis, and mapped according to emerging categories (see Appendix A). Throughout, categories were continually revisited and refined. To be sure, the literature maps derived from this process are not exhaustive but rather begin to shed light on the contrasting conceptions of pathways emerging within prominent strands of the literature surrounding low-carbon transitions.

[1] The following search string was used: (TITLE-ABS-KEY("low-carbon pathway*" OR "decarbonisation pathway*" OR "concentration pathway*" OR "emission* pathway*" OR "transition pathway*")) AND DOCTYPE(ar) AND SUBJAREA(MULT OR ENER OR ENVI OR ARTS OR BUSI OR ECON OR SOCI) AND LANGUAGE(english).

3. Analysis: exploring conceptions of pathways in the context of low-carbon transitions

The term pathway has been used in various ways in the English language. In the broadest sense, it means: (1) "a way that constitutes a path" such as a road; (2) "[a] way of achieving a specified result"; or (3) "a course of action" (Oxford dictionaries, n. d.). Some of its earliest uses appear in religious texts, which employ the term to connote a way of life that is in accordance with biblical teachings, implying the need for shepherding (Dent, 1859; Hill, 1847). In the natural sciences, pathways have long been invoked to describe the chains of nerve cells along which impulses travel (Ungerstedt et al., 1969) or the routes through which a pollutant enters and persists within an ecosystem (Kudo and Mortimer, 1979). In the social sciences, on the other hand, pathways have often been used to represent various patterns of societal development (e.g., Scott and Storper, 1992). Abbott and Snidal (2004, p. 54), for instance, deploy pathways to signify different routes "along which states and other actors can incrementally strengthen international cooperation over time". Similarly, others use pathways to represent development trajectories in science, technology, and industry (Hess, 2007). Although this is only a very brief account of the broader use of pathways, these examples point to some of its general qualities, including (1) movement and (2) change from one state to another. This study, however, is principally concerned with the contrasting interpretations and applications of pathways that have emerged within the study and governance of low-carbon transitions.

This analysis uncovers three core conceptions of pathways in the context of low-carbon transitions, which are constituted by different perspectives and dynamics (see Table 2). The first core conception – referred to here as *biophysical pathways* – is anchored within the climate science research strand and understands pathways as *long-term trajectories of GHG emissions linked to particular stabilization targets and derived from macro-level parameters describing human-climate interactions over time*. In this fashion, the emphasis is on mapping global emissions trajectories spanning diverse atmospheric stabilization levels and associated rates of temperature rise (IPCC, 2014). Given the broad spatial and temporal scales employed (often covering major world regions and several decades or longer), the aim is not to provide specific policy advice but rather to inform climate and earth systems models, impact assessments, and set the context for high-level climate negotiations (Nakićenović, 2000). A second core conception – referred to here as *techno-economic pathways* – is tethered to ideas from technology assessment and economics, understanding pathways as *sequences of techno-economic adjustments linking current sector configurations to desirable low-carbon future states*. In this way, the emphasis is on sector-level changes in technological characteristics (cost/performance improvements, in particular) and investment patterns that lead to new technical configurations, with a number of studies examining energy-related sectors (electricity, industry, buildings, transport, and others) and providing more explicit policy advice (Deep Decarbonization Pathways Project, 2015; Jacobson et al., 2015; Luderer et al., 2012). The third conception – referred to here as *socio-technical pathways* – originates within the socio-technical transitions research strand and views pathways as *unfolding socio-technical patterns of change within societal systems as they move to meet human needs in a low-carbon fashion*. Here the emphasis is on interlocking social and technical (socio-technical) patterns of change within systems meeting particular societal functions such as the provision of electricity (Verbong and Geels, 2010) or transport (Marletto, 2014). In this strand, the normative character of pathways is more explicitly acknowledged. While these three core conceptions are tethered to diverse perspectives and approaches (Geels et al., 2016a), they should not be regarded as mutually exclusive but rather emphasize different yet interlinked dimensions of low-carbon transitions (discussed further in Section 4). The following discussion takes each core conception in turn, identifying the dynamics that mark their character and maturation.

3.1. Biophysical pathways

Starting with the assessment reports on climate change, the IPCC has been largely responsible for popularizing *biophysical pathways*, invoking this conception to explore the "full pathway of emissions to temperature change" (1990a, p. xxxix) and the "many possible pathways to reach stabilization" (1995, p. 9). That is, biophysical pathways embrace both the changing level of emissions over time along with the long-term stabilization or temperature target which it reaches. This conception has been reinforced by prominent imagery (see Fig. 1). Biophysical pathways also recognize that "CO_2 pathways" are underpinned by human systems, often represented by macro-level socio-economic parameters such as "GNP, Energy/GNP, CO_2/Energy" (IPCC, 1990b, p. 37). As this conception is anchored within the natural sciences and reflects the institutional commitments of prominent actors (the IPCC's commitment to policy neutrality, in particular), applications of biophysical pathways tend to distance themselves from political considerations, communicating scientific findings as an ostensibly neutral input for negotiating targets and courses of action. Key contributors to this conception of pathways include core intergovernmental actors such as the IPCC, UNEP, and WMO as well as the applied systems analysis community. However, this conception has been taken up within the broader debate surrounding low-carbon transitions as it forms the basis for the science of climate change. Three dynamics help expose the character and maturation of the biophysical conception of pathways: (1) attempts to map the possibility space around human-

Table 2
Contrasting conceptions of pathways in the context of low-carbon transitions.

Core conceptions	General character of core conceptions	Dynamics exposing the character and maturation of core conceptions	Research strands
Biophysical pathways	Long-term trajectories of GHG emissions linked to particular stabilization targets and derived from macro-level parameters describing human-climate interactions over time	(1) attempts to map the possibility space around human-climate interactions; (2) a growing emphasis on mapping low stabilization levels; and (3) emerging efforts to account for broader socio-economic possibilities	–Climate science
Techno-economic pathways	Sequences of techno-economic adjustments linking current sector configurations to desirable low-carbon future states	(1) the integration of ideas from technology assessment and economics; and (2) the adoption of a somewhat less value and policy neutral orientation	–Technology assessment –Economics
Socio-technical pathways	Unfolding socio-technical patterns of change within societal systems as they move to meet human needs in a low-carbon fashion	(1) the elucidation of transition processes; (2) the deliberate stimulation transitions; and (3) recent efforts to bridge perspectives with quantitative modelling approaches	–Socio-technical transitions

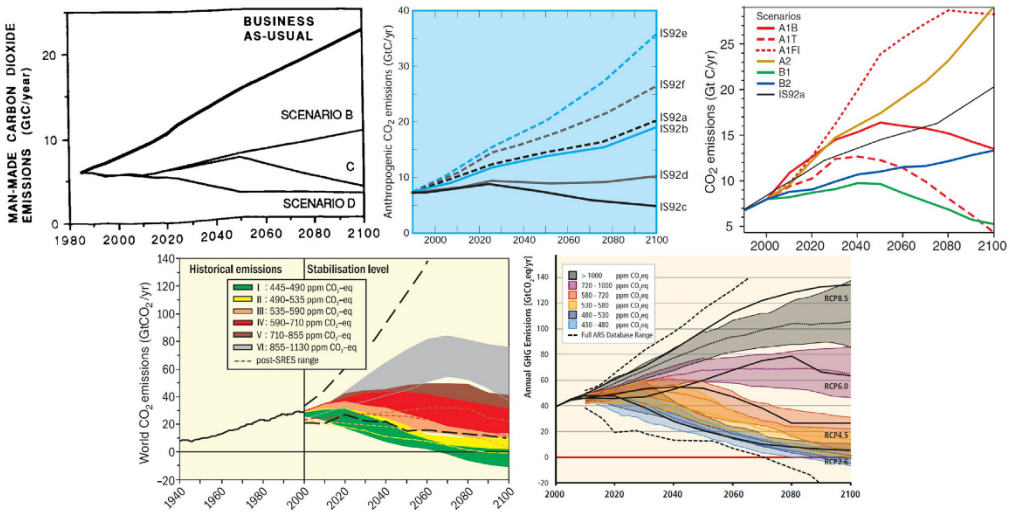


Fig. 1. Prominent imagery associated with biophysical pathways. Images are drawn from the IPCC assessment reports 1–5.

climate interactions; (2) a growing emphasis on mapping low stabilization levels; and (3) emerging efforts to account for broader socio-economic possibilities.

The first dynamic responds to the profound uncertainties and complexities of low-carbon transitions and involves attempts to map the possibility space surrounding climate change through the exploration of a range of biophysical pathways (IPCC, 1990b; Leggett et al., 1992; Nakićenović, 2000; van Vuuren et al., 2011a). In this context, a biophysical pathway can be understood as a "trajectory taken over time to meet different goals for greenhouse gas (GHG) emissions, atmospheric concentrations, or global mean surface temperature change that implies a set of economic, technological and behavioural changes" (IPCC, 2014, p. 1273). And so, while this conception may emphasize emissions and associated concentration levels, it also acknowledges human systems as an input – often in macro-level terms such as global population and CO_2/GDP – for deriving climate processes. Given this, sophisticated computer models are used to explore biophysical pathways informed by different scenarios about the long-term evolution of macro-level socio-economic parameters driving emissions (Girod et al., 2009; Moss et al., 2008). These emissions scenarios vary the timing, shape, and direction of biophysical pathways (e.g., peak and decline or stabilization without overshoot) as "[t]he term 'pathway' emphasizes that not only the long-term concentration levels are of interest, but also the trajectory taken over time to reach that outcome" (Moss et al., 2010, p. 752). In this way, the objective of mapping the possibility space around low-carbon transitions is "to examine the range of plausible future pathways of combined social and environmental systems under conditions of uncertainty . . . and complexity" (Swart et al., 2004, p. 137). Over the past decade, the scenarios used to inform biophysical pathways have increasingly expanded the possibilities with which they engage (see Table 3), reflecting a "broadening of the types and extent of uncertainties that analysts have been willing and able to address" (Metz et al., 2001, p. 20).

A second dynamic follows from this analytical broadening and relates to the growing emphasis on biophysical pathways mapping out low stabilization levels. As "very little information exists on mitigation strategies that could stabilize GHG concentrations at the low levels required to achieve a 2–3 °C temperature target with a high degree of certainty" (van Vuuren et al., 2007, p. 120), a number of more recent studies explore biophysical pathways consistent with low levels of temperature rise (Rogelj et al., 2011). van Vuuren et al. (2011b), in particular, present a biophysical pathway to 1.5–2 °C based on the relatively rapid rollout of a combination of mitigation measures (e.g., low-carbon energy technologies, fuel switching, reforestation, and net-negative emissions using bio-energy and carbon capture and storage) supported by full international cooperation around climate policy. Building on this work, others highlight the tradeoff between immediate mitigation and more extensive net negative emissions later in the century (Sanderson et al., 2016; van Vuuren et al., 2013). In this fashion, applications of biophysical pathways that reach low temperature targets often point to the central role of technological solutions such as the widespread deployment of carbon dioxide removal techniques (Fuss et al., 2014). So, while institutional and behavioral patterns are certainly acknowledged in these analyses (IPCC, 2014, 2007), the "mitigation measures considered in most

Table 3
Scenarios informing the exploration of biophysical pathways.

Scenario Framework	1990 IPCC scenarios	1992 IPCC scenarios	Special report on emissions scenarios	Representative concentration pathways
Used in IPCC assessment reports	1990	1992	1997–2007	2014
Illustrative scenarios	4	6	6	4
Total scenarios	4	6	40	1184 (in scenario database)

This table illustrates the proliferation of scenarios informing the exploration of biophysical pathways. Data for this table are drawn from Girod et al. (2009) and the Fifth Assessment Report Scenario Database.

low greenhouse gas stabilization scenarios focus on reducing emissions by means of alternative technologies" and may pay somewhat less attention to other socio-economic changes that may be needed to avoid dangerous climate impacts (van Vuuren et al., 2011b, p. 114).

A third dynamic concerns efforts to more carefully account for the full range of underlying socio-economic parameters (e.g., Hedenus et al., 2014; van Vuuren et al., 2015). In particular, a new scenario framework is under development, which brings together shared socio-economic pathways (SSPs) and policy assumptions to better inform the exploration of biophysical pathways. The term SSP has been adopted to reflect a greater engagement with "plausible alternative trends in the evolution of society and natural systems over the 21st century at the level of the world and large world regions" (O'Neill et al., 2014, p. 389). To this end, SSPs encompass "two elements: a narrative storyline and a set of quantified measures that define the state of society as it evolves over the 21st century" (Ebi et al., 2014, p. 368). As part of this, there is an attempt to deepen the integration of research communities involved in informing biophysical pathways by using a coordinated and parallel process of scenario development, allowing for greater comparability and the consideration of a broader range of socio-economic possibilities (Edenhofer et al., 2012; Nakićenović et al., 2014).

3.2. Techno-economic pathways

The second core conception of pathways, referred to here as *techno-economic pathways*, has emerged within the literature drawing on ideas from technology assessment and economics. While this conception may take the biophysical processes of climate change as a starting point, it recasts pathways in terms of the more concrete technical and economic processes of technology change within energy-related societal sectors (e.g., electricity, transport, and agriculture) and examines how these sequences of change may lead to low-carbon configurations (see Fig. 2). Bringing this understanding into sharp relief, Johansson et al. (2012, p. 1213) see pathways as "descriptions of demand- and supply-side energy system transformations". Similarly, the IEA (2012, p. 30) explore pathways by which "the link between economic activity, energy demand and emissions can be broken through a transformation of the global energy system and its technologies". Still others develop "different technology pathways to reduce emissions" (OECD, 2012, p. 121). It is important to note however, that while this core conception may take on a distinct character, it continues to draw heavily from biophysical applications of pathways (consider, for instance, the common contributors and shared reliance on quantitative systems models). The main contributors to techno-economic pathways include prominent intergovernmental actors (e.g., IEA and OECD), think tanks (e.g., McKinsey & Company), along with scholarly communities (e.g., engineers and applied systems analysts). Two dynamics mark the ongoing crystallization of the techno-economic conception of pathways: (1) the integration of ideas from technology assessment and economics; and (2) the adoption of a somewhat less value and policy neutral orientation.

With respect to the first dynamic, techno-economic pathways draw upon ideas from technology assessment and economics. While a comprehensive review of these ideas is not possible as modelling approaches vary considerably, this discussion will address a few of the most prominent, including: (1) technical potential, (2) learning rates, (3) rational technology diffusion processes, and (4) carbon pricing as a key driver of technology change. First, assessments of technical potential serve as inputs for techno-economic pathways as they establish an upper threshold

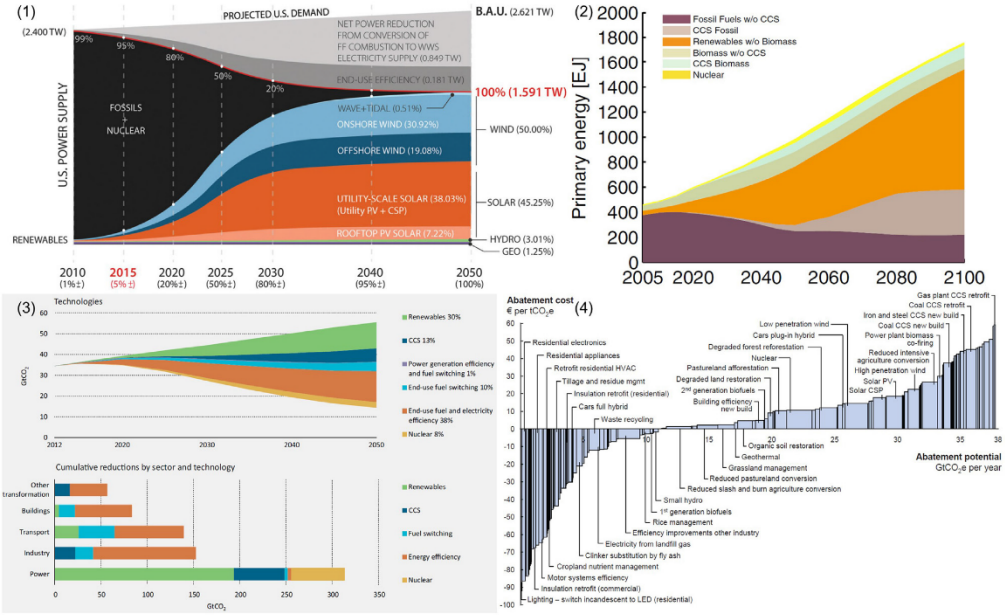


Fig. 2. Prominent imagery associated with techno-economic pathways. This figure illustrates prominent imagery associated with techno-economic pathways, including: changing installed capacity by source over time (Jacobson et al., 2015); changing energy production by source over time (Luderer et al., 2012); changing technology mixes and their individual and cumulative contributions to emissions reductions (International Energy Agency, 2015); and optimal technological deployment sequences, arrayed by abatement cost and emissions reduction potential (McKinsey and Company, 2009).

for the emission reduction capabilities of technologies in the absence of socio-economic constraints (Rosenbloom and Meadowcroft, 2014a). In the case of electricity generating technologies, for instance, assessments of energy production and abatement potential tend to focus on energy resource availability (e.g., solar irradiance), essential technical constraints (e.g., conversion efficiency and capacity factor), energy demand requirements, and the footprint of installed capacity (Archer and Jacobson, 2005; Jacobson et al., 2015; Wiginton et al., 2010). Although additional constraints may be introduced to arrive at an estimate of market potential, the principal goal here is not to envisage socio-politically feasible futures but rather to establish the technical feasibility of particular energy-related sector transformations (e.g., the widespread diffusion of electric vehicles or new renewables) that constitute techno-economic pathways (Jacobson and Delucchi, 2009). Second, the models used in constructing techno-economic pathways tend to draw upon learning rates to project the declining costs and associated diffusion patterns of emerging low-carbon innovations (Amorim et al., 2014; Edenhofer et al., 2009, 2010; International Energy Agency, 2012, 2015; Luderer et al., 2012; McKinsey & Company, 2009). Learning rates "show a simple, quantitative relationship between price and the cumulative production or use of a technology" (IEA, 2000, p. 117), reflecting how research and experience promote performance improvements and cost reductions over time. From this, it is possible to project future time periods where emerging innovations become competitive with conventional technologies or processes, prompting a shift in investment and diffusion patterns (IEA, 2006). Third, modelling exercises informing techno-economic pathways tend to view technology diffusion as proceeding in a relatively rational fashion. That is, models often adopt a set of assumptions (e.g., perfect foresight) that combine to produce optimal diffusion patterns (consider Jägemann et al., 2013; Morrison et al., 2015; Pye and Bataille, 2016 for a review of modelling work). Techno-economic pathways based on abatement cost curves also illustrate this rational diffusion process as they tend to assume technologies are adopted in a stepwise fashion according to cost and relative abatement potential (McKinsey & Company, 2009). Fourth, and correspondingly, technology diffusion within techno-economic pathways is often driven by differing assumptions around the timing, scope, and level of carbon pricing regimes (OECD, 2012, 2008). Taken together, these four ideas demonstrate the rational-economic understanding of technology diffusion which animates much of the work on techno-economic pathways.

In regards to the second dynamic, techno-economic pathways tend to adopt a less value and policy neutral orientation. That is, the aim of techno-economic pathways is no longer to map the possibility space but to scrutinize specific courses of action and offer policy recommendations to decision-makers in government and industry. The IEA (2015), for instance, points to the desirability of a least-cost pathway to decarbonization made up of a portfolio of technologies and facilitated by policy support. Similarly, the Deep Decarbonization Pathways Project (2015) informs decision-makers about the technological and cost implications of different pathways, presenting a menu of contextually appropriate abatement opportunities consistent with deep emissions reductions. Jacobson et al. (2015), on the other hand, make recommendations to reconfigure energy systems according to their preferred pathway (based on wind, water, and solar). Still others focus on cost-efficient pathways based on different technology preferences (Jägemann et al., 2013). According to this core conception, pathways therefore present possible courses of action or sequences of investments to *desirable* end states, using a combination of forecasting and "back-casting" (i.e., working backward from a desirable target and identifying the necessary steps to attain it). The tradeoffs implied by particular techno-economic pathways are an important part of this perspective (e.g., if we exclude certain technologies or processes, how much will it cost to adopt other options). In the face of uncertainty, techno-economic pathways may also serve a role in identifying robust responses and placing these in the context of long-term targets, bridging short-term tactical and long-term strategic thinking (Eom et al., 2015; Levin et al., 2014; Wang and Watson, 2010). Indeed, it has been suggested that "[t]he design of coupled short-and long-term goals should be informed by a plausible pathway to phase out emissions in the long term" (Levin et al., 2014, p. 46). From this, techno-economic pathways may appear inclined toward societal steering approaches based on carbon budgeting (e.g., German Advisory Council on Global Change, 2009), which set long-term goals, establish interim milestones, and monitor performance. However, techno-economic pathways may also lend themselves to market-based approaches that seek to attain targets by inciting low-carbon innovation through the timing, coverage, and level of carbon pricing (OECD, 2009). Taken together, techno-economic pathways relate to the identification of opportunities (concerning the deployment of new innovations), the sequencing of actions and investments, as well as the selection among overarching directions according to certain principles (e.g., economic efficiency).

3.3. Socio-technical pathways

A third core conception of pathways, referred to here as *socio-technical pathways*, is anchored within the strand of research focused on the socio-technical dimensions of low-carbon

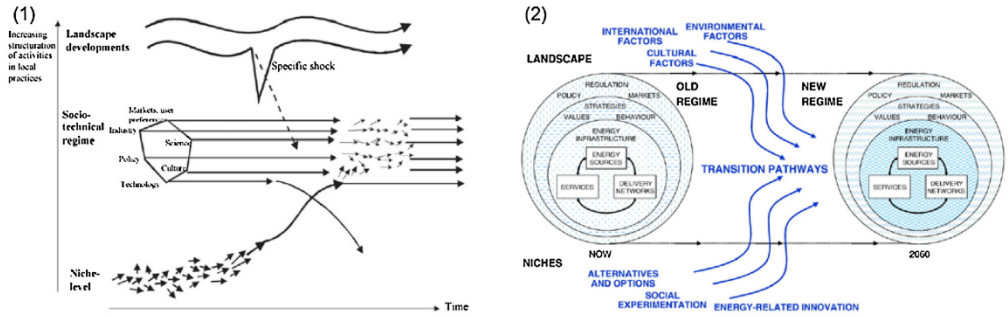


Fig. 3. Prominent imagery associated with socio-technical pathways. This figure illustrates two prominent ways to visualize socio-technical pathways. The first is drawn from Geels and Schot (2007), whereas the second is taken from Foxon et al. (2010).

transitions (for an overview of this literature, consider Markard et al., 2012). The term socio-technical is used to connote the interconnected nature of technological and social change (Geels, 2005a; Hofman et al., 2004). This conception, therefore, moves beyond the biophysical and techno-economic dimensions (as well as rational-economic understandings of innovation) to encompass the broader political, institutional, cultural, and behavioural dynamics relevant to long-term processes of societal change (see Fig. 3). Socio-technical pathways, in this view, are concerned with the multiple and interlocking causal processes involved in transitions, which resonate more closely with narrative approaches (Geels, 2011). Stated differently, transitions "are irreducible to a single cause, factor, or blueprint" (Sovacool, 2016, p. 211). Given this complexity, the aim here is to elucidate the nature, processes, and patterns of socio-technical change. From this, there is a stronger emphasis on historical dynamics both as a means to learn from past episodes of system change and to consider the basis for future transitions. This research strand also tends to engage more explicitly with the normative goals and implications of sustainability transitions. Key contributors to this core conception include scholars focused on the governance of transitions (Kemp et al., 2001; Smith et al., 2005) and the multi-level perspective (Geels and Schot, 2007). Three dynamics mark the character and maturation of the socio-technical conception of pathways: (1) the elucidation of transition processes; (2) the deliberate stimulation of transitions; and (3) recent efforts to bridge perspectives with quantitative modelling approaches.

In regards to the first dynamic, socio-technical pathways are entwined with efforts to elucidate transition processes. Transitions are the way in which societal systems such as transport shift from one socio-technical configuration to another over time (Geels, 2005b). In this fashion, societal systems are constituted by co-evolving material and social elements that fulfill functions as one seamless configuration (e.g., power plants and transmission infrastructure work in concert with regulations, markets, and practices to provide electricity services according to established patterns). Socio-technical pathways, therefore, relate to the nature of transitions and are used to conceptualize the different processes and patterns involved. The multi-level perspective (Geels, 2004; Geels and Schot, 2007), in particular, informs much of the transitions literature and understands socio-technical pathways as unfolding through different patterns of interaction among three levels: the niche, regime, and landscape. The regime represents the incumbent technologies, institutions, and actors that fulfill a societal function. Niches reflect emerging and less developed configurations of innovations, practices, and actor groups. The landscape accounts for broader developments such as cultural shifts and changing political administrations. Some early studies focus on niche-driven socio-technical pathways, elaborating how challenger technologies and actors bring about transitions (Geels, 2002, 2005b). Others, in contrast, consider a greater plurality of pathways, outlining typologies of socio-technical pathways that focus on the role of the regime in modulating transition processes (Berkhout et al., 2004; Smith et al., 2005) as well as the timing and nature of interactions among niche, regime, and landscape (Geels and Schot, 2007).

This early work serves as the basis for more differentiated understandings of socio-technical pathways. Broadly, recent research suggests that socio-technical pathways are: (1) context dependent and deeply temporal (Sovacool, 2016); (2) shaped by competing actors with fluid strategies and positions (Berggren et al., 2015; Marletto, 2014); and (3) not deterministic but rather involve complex feedbacks between structures and agents over time (Foxon et al., 2013; Geels et al., 2016b). Correspondingly, socio-technical pathways not only relate to broad interactions occurring among niche, regime, and landscape but also concern "decision making at critical points" (Foxon et al., 2013, p. 156) and "event-chains and rounds of moves and counter-moves" involving dynamic actor networks (Geels et al., 2016b, p. 898), particularly surrounding key sites of contestation (e.g., regulatory changes and infrastructure investment). Further accentuating the contested nature of socio-technical pathways, a growing body of research focuses on the tendency of powerful actors and institutions to "close down" around a small subset of possibilities that maintain established orientations (Leach et al., 2010a; Smith and Stirling, 2007; Stirling, 2008, 2009). In this view, deploying more participatory approaches that expand the range of worldviews and frames involved in enacting pathways may "open up" the possibilities considered. Indeed, democratizing the development of pathways through "diverse, emergent and unruly political alignments" rather than traditional and more circumscribed policymaking processes could undermine material, institutional, and ideational rigidities (Stirling, 2015, p. 54). Taken together, this leads to a more differentiated understanding of the character of socio-technical pathways, suggesting that they involve continual processes of contestation along with complex and temporally linked feedbacks among agential, material, ideational, and rules systems.

The second dynamic centres on the deliberate stimulation of low-carbon transitions. It takes as a starting point the multi-level interactions previously mentioned, but draws on socio-technical pathways to contemplate the way in which path-dependent regimes based on carbon-intensive configurations may be subverted. Indeed, regimes are long-lasting and resistant to change (Berkhout, 2002). Rules, sunk costs, and vested interests can constrain change processes, locking in established development trajectories (Unruh, 2000). Given the transformative implications of sustainability objectives, this poses a serious challenge for governance. In response, a body of work has emerged which focuses on drawing governance lessons for unlocking transitions (Loorbach and Rotmans, 2010). Socio-technical pathways, therefore, not only represent abstract patterns of change but also the more concrete strategies by which this change might be realized (e.g., Unruh, 2002). In this context, some have focused on the management of niches (Kemp et al., 2001; Verhees et al., 2015), whereas others have examined the role of delegitimization in destabilizing incumbents (Turnheim and Geels, 2012), the "institutional work" of actors in disrupting rule systems (Fuenfschilling and Truffer, 2016), and the potential of opening up deliberative processes to promote transformative change (Leach et al., 2010a; Stirling, 2015). And so, socio-technical pathways are also about identifying opportunities to weaken the multi-layered processes of path dependence and lock-in.

The final dynamic involves increasing efforts to bridge socio-technical and quantitative modelling perspectives informing the development of low-carbon pathways. Spanning disciplinary divides, quantitative systems modelling techniques have been employed to elucidate dynamic interactions among actors (Bergman et al., 2008) and to consider potential sequences of adjustments to societal systems as they move along socio-technical pathways (Foxon, 2013). While some have complemented narratives with formal modelling (Bergman et al., 2008; Foxon, 2013; Papachristos, 2014), others have brought the different approaches into dialogue with one another, juxtaposing and further scrutinizing the results of both exercises (McDowall, 2014). Building on this, a more substantial project to bridge perspectives has been initiated by Turnheim et al. (2015, p. 246), asserting that "it is only by connecting insights from different approaches and cross-examining transitions through their combined perspectives that we may reach a more robust understanding of sustainability transitions". This work bridges social science and climate science perspectives on pathways to capture the "essential

phenomenological attributes of transitions pathways: goal-setting (orientation towards collective normative objectives), momentum (relative to inertia and incremental change in existing regimes), depth (degree of radicality of systems change) and scope (number of dimensions that change in socio-technical systems)" (p. 248). Thus, pathways are already playing a role as a bridging concept, bringing diverse approaches and perspectives together in dialogue in order to frame the challenge of low-carbon transitions.

4. Discussion and conclusions

This analysis exposes three core conceptions of pathways in the context of low-carbon transitions, each of which emphasizes different dimensions of this societal challenge: (1) biophysical, (2) techno-economic, and (3) socio-technical. That is, core conceptions of pathways highlight different elements of human and natural systems that are anticipated to undergo change as low-carbon transitions unfold (see Fig. 4). While biophysical pathways underline changing emissions over time that lead to different concentration levels and temperature targets at the global scale, techno-economic pathways focus on changing investment patterns and technological configurations at the sector level (mainly national energy-related sectors). Socio-technical pathways, in contrast, emphasize patterns of material and social change at the level of societal systems (mainly national, regional, or local socio-technical systems). In this fashion, core conceptions of pathways can be viewed as interlinked at different *yet overlapping* spatial (from global to sector to societal systems levels) and analytical (from climate to technology to social patterns) scales. This suggests that low-carbon pathways are multifaceted and cannot be usefully reduced to a single dimension as changing levels of aggregate emissions are underpinned by specific investments in technologies that, in turn, imply particular socio-political arrangements (e.g., if low stabilization targets point to the widespread adoption of carbon dioxide removal techniques, what might this suggest for cultural and political patterns). Focusing on a single dimension may, therefore, inadvertently mask the full complexity of low-carbon transitions. In the case of biophysical and techno-economic pathways, for instance, there may be a tendency to accentuate what are seemingly more tractable aspects of human-climate interactions (e.g., technological mitigation responses), potentially neglecting the longstanding practices, institutions, and political arrangements that underpin current carbon-intensive societies (Keary, 2016). Conversely, socio-technical pathways may emphasize options that do not correspond with stabilization targets or measures of technical feasibility (McDowall, 2014). So, if the concept of pathways is to usefully frame the complex character of decarbonization, closer bridges between perspectives will be needed. This bridging of perspectives is already underway as research strands begin to coalesce around the use of the concept of pathways in low-carbon transitions, enriching interdisciplinary dialogue (Foxon et al., 2013; Geels et al., 2016a; O'Neill et al., 2014; Turnheim et al., 2015). That is not to say, however, that there are not also risks if epistemic traditions are too closely entwined (see Andersson et al., 2014 for a discussion of potential risks), suggesting that the multi-dimensionality of pathways may best be appreciated through a plurality rather than fusion of perspectives.

This exploration also reveals a series of attributes possessed by core conceptions of pathways (see Table 4). First, the expanding use of the concept of pathways arises from an overarching project to engage with the uncertainty and complexity of sustainability challenges (Swart et al., 2004). This engagement underlies the effort to broaden and deepen the possibility space mapped by biophysical pathways (Moss et al., 2010). It also forms an essential part of techno-economic pathways, which often seek to identify transformation strategies that are robust across diverging circumstances and future states (Deep Decarbonization Pathways Project, 2015). Socio-technical pathways, on the other hand, respond to uncertainty and complexity by recognizing the multitude of

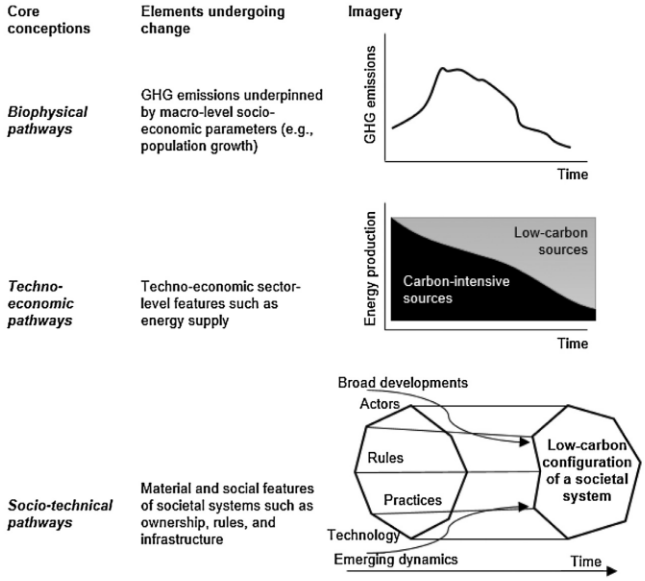


Fig. 4. The multi-dimensionality of pathways.

Table 4
Key attributes of the core conceptions of pathways in the context of low-carbon transitions.

Core conceptions	Complexity and uncertainty	Innovation and inertia	Temporality	Governance	Normativity
Biophysical pathways	Mapping the possibility space	Emphasis on rational economic processes (e.g., broad-based carbon pricing)	Emphasis on the future	Mixed (emphasis on market-based approaches)	Value and policy neutral
Techno-economic pathways	Identifying robust options	Emphasis on rational economic processes (e.g., cost/performance change)	Linking present and future	Mixed (emphasis on market-based approaches)	Less value and policy neutral
Socio-technical pathways	Accounting for varying patterns and interactions	Broad representation of processes (e.g., culture and politics)	Linking past, present, and future	Mixed (emphasis on societal steering and participatory processes)	Explicit engagement with values and implications for policy advice

The categories in this table are adapted from Turnheim et al. (2015).

different system configurations that may emerge depending on historical contingencies and unfolding patterns of social and material interactions (Foxon et al., 2013). Second, although each of the core conceptions of pathways acknowledge the importance of innovation and inertia, they emphasize different forces underlying these processes. Biophysical and techno-economic pathways tend to emphasize rational-economic factors such as the relative cost/performance level of technologies (McKinsey & Company, 2009) and incentive/disincentive structures such as carbon pricing (van Vuuren et al., 2011b, 2013). Socio-technical pathways, in contrast, sacrifice the precision of formalized models in order to attend to a wider array of social and material forces that may constrain or enable innovation (Berkhout, 2002; Geels, 2005b). Third, core conceptions of pathways are predisposed to particular temporal scopes, presenting different implications for their use in decision-making. Biophysical pathways, for instance, "focus on century time scales [and] are less suitable for analysis of near term (a decade or less) developments" (Nakićenović, 2000, p. 11). Techno-economic pathways, in comparison, tend to pay more attention to immediate courses of action and how these might link current and future states (Eom et al., 2015; McKinsey & Company, 2010). Socio-technical pathways bring together past, present, and future dynamics. Fourth, conceptions of pathways appear to accommodate a variety of governance approaches. While some conceptions resonate more closely with societal steering (e.g., long-term targets achieved through continuous intervention, monitoring, and updating), there are also opportunities to institutionalize applications of pathways within market-based approaches (e.g., long-term targets achieved through emissions pricing) and even more participatory decision-making processes (discussed further below). Lastly, core conceptions of pathways display diverging normative inclinations, particularly with respect to value judgements and the role of science in policy. As biophysical pathways are predominantly anchored in the natural sciences debate (with its affinity toward positivist ontological and epistemological assumptions), this conception tends to be predisposed to value and policy neutrality. In this way, biophysical pathways attempt to keep scientific findings separate from political considerations (Pielke, 2006). Techno-economic pathways are similarly inclined toward positivist ontological and epistemological assumptions, yet offer policy recommendations based upon implicit value judgements (e.g., the centrality of efficiency) that may mask political and ethical questions. In marked contrast, socio-technical pathways make crossovers to a number of ontologies (Geels, 2010) and problematize normative positions (Turnheim et al., 2015), exposing tensions between competing values and interests.

So, what does this exploration of pathways imply for the usefulness of this concept in the context of governing low-carbon transitions? As mentioned, "pathways" shows promise as a bridging concept, bringing to bear the diverse perspectives needed to grapple with the complexity and uncertainty presented by low-carbon transitions. However, if the concept is cast too strongly in terms of individual core conceptions, there may be a tendency to emphasize certain dynamics over others and inadvertently underappreciate the complexity of the decarbonization challenge. If, on the one hand, low-carbon transitions are framed exclusively in terms of socio-technical pathways, the concept may only permit a "limited assessment of sustainability outcomes and achievement of future targets" (Geels et al., 2016a, p. 580) – central concerns of mitigating this societal challenge. On the other hand, biophysical and techno-economic conceptions, if taken in isolation, have the potential to obscure value judgements and elide the political tradeoffs that are essential parts of decarbonization (e.g., the continual negotiation of tensions between economic, environmental, and other objectives), preferring instead to reconcile these tradeoffs with rational-economic trajectories of technology change. While technology change is undeniably critical to devising plausible low-carbon pathways, it remains equally important to

Table 5
Functions of the concept of pathways in the governance and theory of low-carbon transitions.

Function	Examples
Mapping	- Exploring possible futures based on some combination of: historical developments, present circumstances, emerging trends, and assumptions about long-run dynamics in human and natural systems
Planning	- Placing near-term decisions in the context of long-term outcomes - Scrutinizing the consequences and tradeoffs of choices and options
Learning	- Identifying key patterns and processes involved in technological and social change
Bridging	- Bringing a plurality of perspectives and approaches together in constructive dialogue
Communicating	- Facilitating the flow of information about possibilities, choices, and tradeoffs among broad constituencies

seriously engage with the political challenges and the stickier social dimensions. Transitions to sustainability are inherently political, involving protracted processes of conflict and contestation among interests and priorities. In this fashion, the promise of the concept of pathways is not simply to incorporate long-term climate considerations into policy and planning but also to help negotiate among priorities by exposing the implications (political or otherwise) of immediate choices for long-term objectives around climate change, economic development, and even sustainability more broadly. By more explicitly exposing the tradeoffs embodied by choices, a pathways frame may help to broaden and deepen debates surrounding the possibilities pursued to unlock low-carbon transitions. This is not to say, however, that the deployment of the concept of pathways in governance should suggest a relatively smooth or managed process of change. Indeed, this belies the disruptive interventions, unintended consequences, and "wild card" events that may trigger transformational changes in human and natural systems (Walsh et al., 2015). As Meadowcroft (2009, p. 323) reminds us, the societal transition to low-carbon arrangements "will prove to be a messy, conflictual, and highly disjointed process".

From this discussion, it may also be possible to form some initial impressions about the functions of the concept of pathways in practice and theory (see Table 5). Taking the various conceptions into consideration, findings suggest that a central role of the concept of pathways is to link present circumstances to long-run decarbonized futures in the context of deep uncertainty and complexity, while mediating among priorities and attending to the consequences of choices. This role is fulfilled through five key functions of the concept: (1) mapping, (2) planning, (3) learning, (4) bridging, and (5) communicating. Mapping involves exploring a range of possible futures; planning relates to more concrete decisions involved in identifying suitable responses and plotting a course toward desirable futures; learning is primarily concerned with drawing lessons about change processes; bridging, as mentioned, involves bringing together the diverse perspectives needed to gain traction on uncertainty and complexity; whereas, communicating involves mobilizing knowledge and encouraging the open flow of intelligible information about low-carbon possibilities, choices, and tradeoffs among broad constituencies (scholarly disciplines and expert communities, but also industry, civil society, and the general public). Although the bridging function is still in its infancy, there may be opportunities to deploy applications of pathways as part of governance approaches that bring together and negotiate among contending interests and priorities. In this fashion, functions may work in concert (bridging and planning, in the above case) with some manifestations only just beginning to emerge.

Beyond this, there is also merit in pointing to other facets of the concept of pathways that have, to date, received more limited attention. In particular, more can still be done to (1) interrogate the politics of choices at critical junctures (Foxon et al., 2013) and (2) explore the evolving character of society, lifestyle patterns, and social practices (Shove et al., 2015; Shove and Walker, 2014). First, while Foxon et al. (2013) and others (Geels et al., 2016b; Hughes et al., 2013; Stirling, 2014) have begun to elucidate how choices at critical points can lead pathways to branch off in different directions, there is room to further scrutinize the contestation and implications of choices at key junctures (e.g., the renewal of institutional commitments or infrastructure). In this view, low-carbon pathways are not solely defined by general patterns and directions, but rather the specific sequence of choices that enable or constrain possibilities. Consider, for instance, how the renewal of long-lived nuclear reactors, the availability of technological options (e.g., no carbon capture and storage), or even the gradual enhancement of conservation programs might shape long-term climate mitigation strategies. This suggests that choices layer and interact over time, displaying a degree of irreversibility. And, perhaps most importantly, each of these choices are linked to contending material interests, frames of reference, and visions for the future that suggest radically different low-carbon pathways (Rosenbloom and Meadowcroft, 2014b). The electrification of transport, for instance, not only represents a way to decarbonize a significant source of energy demand but also reflects a critical political challenge to fossil fuel interests and an opportunity for automotive industries, particularly if public funds are leveraged to promote the rapid adoption of electric vehicles and the deployment of enabling infrastructure (Meadowcroft, 2016). If these sites of contestation are further exposed by applications of pathways, the concept (as it becomes institutionalized in governance frameworks) may form the basis for more deliberate and participatory approaches to the governance of low-carbon transitions (perhaps akin to the "Pathways Approach" outlined in Leach et al., 2010b, 2010a). This may enable the negotiation and reconciliation (where possible) of competing interests and even the appreciation of alternative visions for change (Stirling, 2009, 2015).

Second, the concept of pathways has yet to fully embrace the implications of low-carbon transitions for lifestyles and the character of broader society. This is of particular importance as, at base, conceptions of pathways aim to tell plausible stories about large-scale transformations occurring over multi-decadal timescales. As energy is central to decarbonization and is deeply intertwined with the social patterns around its use (e.g., travel, comfort, diet, and meal preparation), these stories must also grapple with evolving social arrangements emerging alongside technical, economic, and biophysical adjustments. Indeed, social practices and patterns of perceived need surrounding energy are not fixed across time, contexts, and cultures (Shove, 2014; Strengers and Maller, 2012; Walker et al., 2014). Rather, "technological configurations, everyday life routines, knowledge, and motivation constitute the practice and also structure the possibilities for change" (Gram-Hanssen, 2009, p. 150). In this fashion, it is not only important for applications of pathways to account for the way in which social patterns evolve alongside biophysical and techno-economic factors but also to consider how these patterns (e.g., living arrangements as well as work and recreation) might shape climate mitigation strategies. The conservation component of low-carbon pathways, for instance, might suggest a more serious engagement with reversing problematic social practices around heating and cooling (Shove et al., 2014). And, the way in which these changes unfold will have serious implications for distributional concerns around energy access (Newell and Mulvaney, 2013) and compatible systems of governance (Gilley, 2012). This also raises important questions about how to simultaneously devise *liveable, equitable, and low-carbon* future states within applications of pathways, with the aim of creating compelling futures while remaining wary of overly optimistic techno-centric visions. To be sure, a number of applications of pathways already attempt to grapple with these factors, including contributions to socio-technical pathways as well as a growing body of work on "community pathways" (German Advisory Council on Global Change, 2016; Wilson, 2012). However, social practice and lifestyle considerations have yet to deeply penetrate the mainstream climate mitigation debate that is primarily focused on biophysical and techno-economic core conceptions (and the correspondingly more rational-economic understandings of human behavior).

Taken together, this exploration suggests that "pathways" represents a promising bridging concept that is beginning to usefully frame low-carbon transitions. Despite this promise, however, the concept also presents important issues which point

to the need for further reflexivity around its deployment in the debates and analytical approaches that surround climate change mitigation. In this way, the concept of pathways can still be considered a work in progress, requiring additional efforts to bridge plural perspectives and to more fully embrace the complexities of low-carbon transitions. At the broadest level, this study demonstrates that key political concepts such as pathways are never fully resolved but rather evolve overtime and become increasingly layered as different perspectives contribute to and struggle over their development.

Acknowledgements

The author acknowledges the support of the Social Sciences and Humanities Research Council of Canada. I would like to thank James Meadowcroft for his valuable feedback on the paper as well as the three anonymous reviewers for their insightful comments.

Appendix A.

See Figs. 1A–3A .

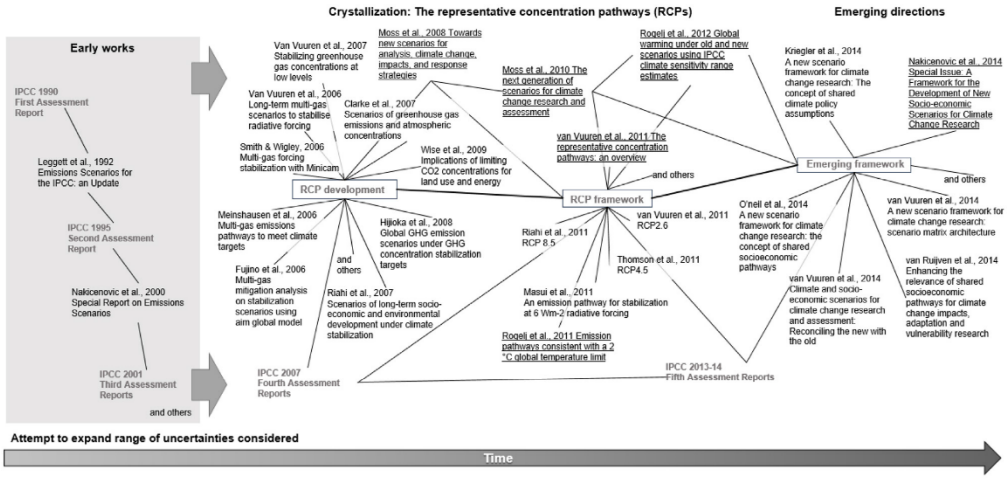


Fig. 1A. Map of selected contributions to biophysical pathways. This figure maps the interconnections and mutual enrichment among selected contributions to the biophysical conception of pathways. Solid connecting lines reflect relatively close linkages among contributions (ideas are cited and inform the analysis). IPCC assessments and scenario frameworks are presented in light grey, whereas syntheses of the literature are underlined.

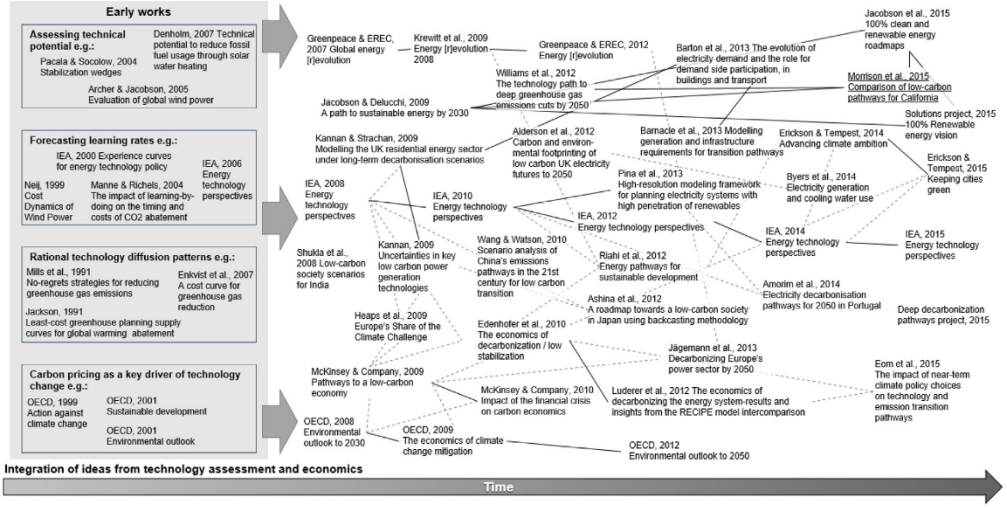


Fig. 2A. Map of selected contributions to techno-economic pathways. This figure maps the interconnections and mutual enrichment among selected contributions to the techno-economic conception of pathways. Dotted lines represent indirect connections (ideas are cited but may not be applied), whereas solid lines reflect more direct linkages (ideas are cited and more closely inform the analysis). Syntheses of the literature are underlined.

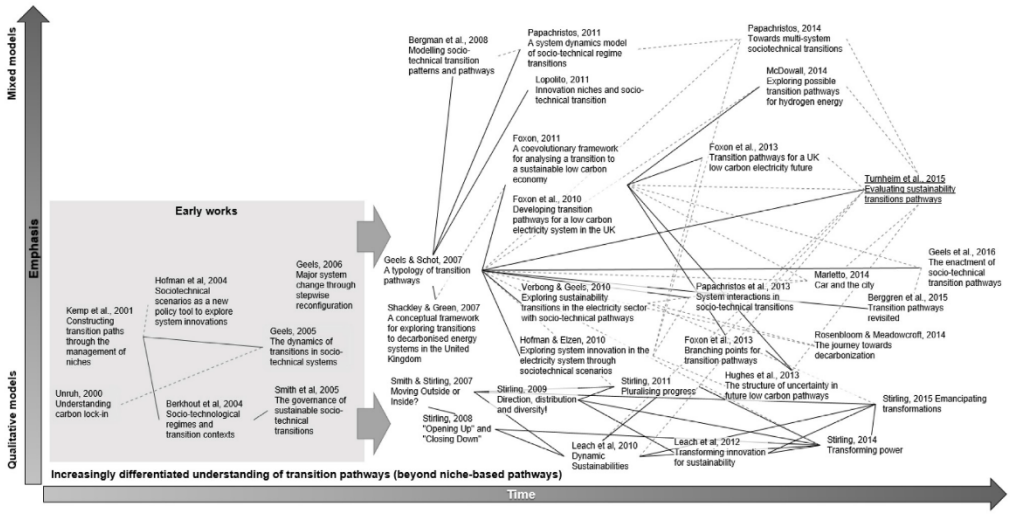


Fig. 3A. Map of selected contributions to socio-technical pathways. This figure maps the interconnections and mutual enrichment among selected contributions to the socio-technical conception of pathways. Dotted lines represent indirect connections (ideas are cited but may not be applied), whereas solid lines reflect more direct linkages (ideas are cited and more closely inform the analysis). Syntheses of the literature are underlined.

References

Abbott, K.W., Snidal, D., 2004. Pathways to international cooperation. In: Benvenisti, E., Hirsch, M. (Eds.), The Impact of International Law on International Cooperation: Theoretical Perspectives. Cambridge University Press, pp. 50–84.

Amorim, F., Pina, A., Gerbelová, H., Pereira da Silva, P., Vasconcelos, J., Martins, V., 2014. Electricity decarbonisation pathways for 2050 in Portugal: a TIMES (The Integrated MARKAL-EFOM System) based approach in closed versus open systems modelling. Energy 69, 104–112. doi:http://dx.doi.org/10.1016/j.energy.2014.01.052.

Andersson, C., Törnberg, A., Törnberg, P., 2014. Societal systems – complex or worse? Futures 63, 145–157. doi:http://dx.doi.org/10.1016/j.futures.2014.07.003.

Archer, C.L., Jacobson, M.Z., 2005. Evaluation of global wind power. J. Geophys. Res. Atmos. 110, 1–20. doi:http://dx.doi.org/10.1029/2004JD005462.

Berggren, C., Magnusson, T., Sushandoyo, D., 2015. Transition pathways revisited: established firms as multi-level actors in the heavy vehicle industry. Res. Policy 44, 1017–1028. doi:http://dx.doi.org/10.1016/j.respol.2014.11.009.

Bergman, N., Haxeltine, A., Whitmarsh, L., Köhler, J., Schilperoord, M., Rotmans, J., 2008. Modelling socio-technical transition patterns and pathways. J. Artif. Soc. Soc. Simul. 11, 7.

Berkhout, F., Smith, A., Stirling, A., 2004. Socio-technological regimes and transition contexts. System Innovation and the Transition to Sustainability: Theory, Evidence and Policy. Edward Elgar Cheltenham, pp, pp. 48–75.

Berkhout, F., 2002. Technological regimes, path dependency and the environment. Glob. Environ. Change 12, 1–4.

Collier, D., Daniel Hidalgo, F., Olivia Maciuceanu, A., 2006. Essentially contested concepts: debates and applications. J. Polit. Ideol. 11, 211–246. doi:http://dx.doi.org/10.1080/13569310600923782.

Davoudi, S., Shaw, K., Haider, L.J., Quinlan, A.E., Peterson, G.D., Wilkinson, C., Fünfgeld, H., McEvoy, D., Porter, L., 2012. Resilience: a bridging concept or a dead end? Reframing resilience: challenges for planning theory and practice interacting traps: resilience assessment of a pasture management system in northern Afghanistan urban resilience: what does it mean in planning practice? Resilience as a useful concept for climate change adaptation? The politics of resilience for planning: a cautionary note. Plan. Theory Pract. 13, 299–333. doi:http://dx.doi.org/10.1080/14649357.2012.677124.

Deep Decarbonization Pathways Project, 2015. Pathways to Deep Decarbonization 2015 Report. SDSN – IDDRI.

Dent, A., 1859. The Plain Man's Pathway to Heaven, Wherein Every Man May Clearly See Whether He Shall Be Saved or Damned, with a Table of All the Principal Matters, and Three Prayers Necessary to Be Used in Private Families, Hereunto Added. Belfast, North of Ireland Bk. [and] Tract Depository.

Ebi, K.L., Hallegatte, S., Kram, T., Arnell, N.W., Carter, T.R., Edmonds, J., Kriegler, E., Mathur, R., O'Neill, B.C., Riahi, K., Winkler, H., van Vuuren, D.P., Zwickel, T., 2014. A new scenario framework for climate change research: background, process, and future directions. Clim. Change 122, 363–372. doi:http://dx.doi.org/10.1007/s10584-013-0912-3.

Edenhofer, O., Carraro, C., Hourcade, K., Neuhoff, K., Luderer, G., Flachsland, C., Jakob, M., Popp, A., Steckel, J., Strohschein, J., Bauer, N., Brunner, S., Leimbach, M., Lotze-Campen, H., Bosetti, V., Cian, E., Tavoni, M., Sassi, O., Waisman, H., Crassous-Doerfler, R., Monjon, S., Dröge, S., Essen, H.V., Rio, P.D., Türk, A., 2009. The Economics of Decarbonization – Report of the RECIPE Project. Potsdam Institute for Climate Impact Research, Postdam.

Edenhofer, O., Knopf, B., Barker, T., Baumstark, L., Bellevrat, E., Chateau, B., Criqui, P., Isaac, M., Kitous, A., Kypreos, S., Leimbach, M., Lessmann, K., Magné, B., Scrieciu, Ş., Turton, H., Van Vuuren, D.P., 2010. The economics of low stabilization: model comparison of mitigation strategies and costs. Energy J. 31, 11–48.

Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Barros, V.R., Field, C.B., Zwickel, T., Schlömer, S., Ebi, K.L., Mastrandrea, M.D., Mach, K.J., von Stechow, C. (Eds.), 2012. IPCC Workshop on Socio-economic Scenarios: Workshop Report. IPCC, Berlin.

Eom, J., Edmonds, J., Krey, V., Johnson, N., Longden, T., Luderer, G., Riahi, K., Van Vuuren, D.P., 2015. The impact of near-term climate policy choices on technology and emission transition pathways. Technol. Forecast. Soc. Change 90, 73–88. doi:http://dx.doi.org/10.1016/j.techfore.2013.09.017.

Fischer, F., Forester, J. (Eds.), 1993. The Argumentative Turn in Policy Analysis and Planning. Duke University Press, Durham.

Foxon, T.J., Hammond, G.P., Pearson, P.J.G., 2010. Developing transition pathways for a low carbon electricity system in the UK. Technol. Forecast. Soc. Change 77, 1203–1213. doi:http://dx.doi.org/10.1016/j.techfore.2010.04.002.

Foxon, T.J., Pearson, P.J.G., Arapostathis, S., Carlsson-Hyslop, A., Thornton, J., 2013. Branching points for transition pathways: assessing responses of actors to challenges on pathways to a low carbon future. Energy Policy 52, 146–158. doi:http://dx.doi.org/10.1016/j.enpol.2012.04.030.

Foxon, T.J., 2013. Transition pathways for a UK low carbon electricity future. Energy Policy 52, 10–24. doi:http://dx.doi.org/10.1016/j.enpol.2012.04.001.

Fuenfschilling, L., Truffer, B., 2016. The interplay of institutions, actors and technologies in socio-technical systems – an analysis of transformations in the Australian urban water sector. Technol. Forecast. Soc. Change 103, 298–312. doi:http://dx.doi.org/10.1016/j.techfore.2015.11.023.

Fuss, S., Canadell, J.G., Peters, G.P., Tavoni, M., Andrew, R.M., Ciais, P., Jackson, R.B., Jones, C.D., Kraxner, F., Nakicenovic, N., Le Quéré, C., Raupach, M.R., Sharifi, A., Smith, P., Yamagata, Y., 2014. Betting on negative emissions. Nat. Clim. Change 4, 850–853. doi:http://dx.doi.org/10.1038/nclimate2392.

G7, 2015. Think Ahead Act Together. Leader's Declaration. Group of seven, Elmau.

Gamson, W.A., Modigliani, A., 1987. The changing culture of affirmative action. In: Braungart, R.G. (Ed.), Research in Political Sociology. JAI Press, Greenwich pp. 137–177.

Geels, F.W., Schot, J., 2007. Typology of sociotechnical transition pathways. Res. Policy 36, 399–417. doi:http://dx.doi.org/10.1016/j.respol.2007.01.003.

Geels, F.W., Berkhout, F., van Vuuren, D.P., 2016a. Bridging analytical approaches for low-carbon transitions. Nat. Clim. Change 6, 576–583. doi:http://dx.doi.org/10.1038/nclimate2980.

Geels, F.W., Kern, F., Fuchs, G., Hinderer, N., Kungl, G., Mylan, J., Neukirch, M., Wassermann, S., 2016b. The enactment of socio-technical transition pathways:

a reformulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990–2014). Res. Policy 45, 896–913. doi:http://dx.doi.org/10.1016/j.respol.2016.01.015.
Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Res. Policy 31, 1257–1274.
Geels, F.W., 2004. From sectoral systems of innovation to socio-technical systems. Res. Policy 33, 897–920. doi:http://dx.doi.org/10.1016/j.respol.2004.01.015.
Geels, F.W., 2005a. Processes and patterns in transitions and system innovations: refining the co-evolutionary multi-level perspective. Technol. Forecast. Soc. Change 72, 681–696. doi:http://dx.doi.org/10.1016/j.techfore.2004.08.014.
Geels, F.W., 2005b. The dynamics of transitions in socio-technical systems: a multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860–1930). Technol. Anal. Strateg. Manag. 17, 445–476.
Geels, F.W., 2010. Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. Res. Policy 39, 495–510. doi:http://dx.doi.org/10.1016/j.respol.2010.01.022.
Geels, F.W., 2011. The multi-level perspective on sustainability transitions: responses to seven criticisms. Environ. Innov. Soc. Transit. 1, 24–40. doi:http://dx.doi.org/10.1016/j.eist.2011.02.002.
German Advisory Council on Global Change, 2009. Solving the Climate Dilemma: the Budget Approach; Special Report. WBGU, Berlin.
German Advisory Council on Global Change, 2016. Humanity on the Move: Unlocking the Transformative Power of Cities. WBGU, Berlin.
Gilley, B., 2012. Authoritarian environmentalism and China's response to climate change. Environ. Polit. 21, 287–307. doi:http://dx.doi.org/10.1080/09644016.2012.651904.
Girod, B., Wiek, A., Mieg, H., Hulme, M., 2009. The evolution of the IPCC's emissions scenarios. Environ. Sci. Policy 12, 103–118. doi:http://dx.doi.org/10.1016/j.envsci.2008.12.006.
Gram-Hanssen, K., 2009. Standby consumption in households analyzed with a practice theory approach. J. Ind. Ecol. 14, 150–165. doi:http://dx.doi.org/10.1111/j.1530-9290.2009.00194.x.
Hedenus, F., Wirsenius, S., Johansson, D.J.A., 2014. The importance of reduced meat and dairy consumption for meeting stringent climate change targets. Clim. Change 124, 79–91. doi:http://dx.doi.org/10.1007/s10584-014-1104-5.
Hess, D.J., 2007. Alternative Pathways in Science and Industry: Activism, Innovation, and the Environment in an Era of Globalization, Urban and Industrial Environments. MIT Press, Cambridge.
Hill, R., 1847. The Pathway to Piety. Pickering, London.
Hofman, P.S., Elzen, B., Geels, F.W., 2004. Sociotechnical scenarios as a new policy tool to explore system innovations: co-evolution of technology and society in the Netherlands electricity domain. Innov. Manag. Policy Pract. 6, 344–360. doi:http://dx.doi.org/10.5172/impp.2004.6.2.344.
Hughes, N., Strachan, N., Gross, R., 2013. The structure of uncertainty in future low carbon pathways. Energy Policy 52, 45–54. doi:http://dx.doi.org/10.1016/j.enpol.2012.04.028.
International Energy Agency, 2000. Experience Curves for Energy Technology Policy. OECD/IEA, Paris.
International Energy Agency, 2006. Energy Technology Perspectives 2006: Scenarios & Strategies to 2050. OECD/IEA, Paris.
IPCC, 1990a. Climate Change 1990: IPCC First Assessment Report. World Meteorological Organization, Geneva.
IPCC, 1990b. Climate Change: The IPCC Response Strategies. World Meteorogical Organization & United Nations Environmental Program.
IPCC, 1995. Climate Change 1995: IPCC Second Assessment Report. .
IPCC, 2007. Climate Change 2007: Mitigation of Climate Change: Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge; New York.
IPCC, 2014. Climate Change 2014: Mitigation of Climate Change: Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
International Energy Agency, 2012. Energy Technology Perspectives 2012: Pathways to a Clean Energy System. OECD/IEA, Paris.
International Energy Agency, 2015. Energy Technology Perspectives 2015: Mobilising Innovation to Accelerate Climate Action. OECD/IEA, Paris.
Jägemann, C., Fürsch, M., Hagspiel, S., Nagl, S., 2013. Decarbonizing Europe's power sector by 2050 – analyzing the economic implications of alternative decarbonization pathways. Energy Econ. 40, 622–636. doi:http://dx.doi.org/10.1016/j.eneco.2013.08.019.
Jacobson, M.Z., Delucchi, M.A., 2009. A path to sustainable energy by 2030. Sci. Am. 301, 58–65.
Jacobson, M.Z., Delucchi, M.A., Bazouin, G., Bauer, Z.A.F., Heavey, C.C., Fisher, E., Morris, S.B., Piekutowski, D.J.Y., Vencill, T.A., Yeskoo, T.W., 2015. 100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for the 50 United States. Energy Environ. Sci 8, 2093–2117. doi:http://dx.doi.org/10.1039/C5EE01283J.
Johansson, T.B., Nakićenović, N., Patwardhan, A., Gomez-Echeverri, L. (Eds.), 2012. Global Energy Assessment (GEA): Toward a Sustainable Future. Cambridge University Press, Cambridge.
Keary, M., 2016. The new prometheans: technological optimism in climate change mitigation modelling. Environ. Values 25, 7–28. doi:http://dx.doi.org/10.3197/096327115X14497392134801.
Kemp, R., Rip, A., Schot, J.W., 2001. Constructing transition paths through the management of niches. In: Garud, R., Karnoe, P. (Eds.), Path Dependence and Creation. Lawrence Erlbaum, Mahwa (N.J.) and London, pp. 269–299.
Kudo, A., Mortimer, D.C., 1979. Pathways for mercury uptake by fish from bed sediments. Environ. Pollut. 1970 (19), 239–245.
Leach, M., Scoones, I., Stirling, A., 2010a. Dynamic Sustainabilities: Technology, Environment, Social Justice. Earthscan.
Leach, M., Scoones, I., Stirling, A., 2010b. Governing epidemics in an age of complexity: narratives, politics and pathways to sustainability. Glob. Environ. Change 20, 369–377. doi:http://dx.doi.org/10.1016/j.gloenvcha.2009.11.008.
Leggett, J., Pepper, W.J., Swart, R.J., Edmonds, J., Meira Filho, L.G., Mintzer, I., Wang, M.X., 1992. Emissions Scenarios for the IPCC: an Update. .
Levin, K., Finnegan, J., Rich, D., Bhatia, P., 2014. Mitigation Goal Standard: An Accounting and Reporting Standard for National and Subnational Greenhouse Gas Reduction Goals. World Resources Institute, Washington, D.C.
Loorbach, D., Rotmans, J., 2010. The practice of transition management: examples and lessons from four distinct cases. Futures 42, 237–246. doi:http://dx.doi.org/10.1016/j.futures.2009.11.009.
Luderer, G., Bosetti, V., Jakob, M., Leimbach, M., Steckel, J.C., Waisman, H., Edenhofer, O., 2012. The economics of decarbonizing the energy system—results and insights from the RECIPE model intercomparison. Clim. Change 114, 9–37. doi:http://dx.doi.org/10.1007/s10584-011-0105-x.
Markard, J., Raven, R., Truffer, B., 2012. Sustainability transitions: an emerging field of research and its prospects. Res. Policy 41, 955–967. doi:http://dx.doi.org/10.1016/j.respol.2012.02.013.
Marletto, G., 2014. Car and the city: socio-technical transition pathways to 2030. Technol. Forecast. Soc. Change 87, 164–178. doi:http://dx.doi.org/10.1016/j.techfore.2013.12.013.
McDowall, W., 2014. Exploring possible transition pathways for hydrogen energy: a hybrid approach using socio-technical scenarios and energy system modelling. Futures 63, 1–14. doi:http://dx.doi.org/10.1016/j.futures.2014.07.004.
McGann, J., 2015. 2014 Global Go to Think Tank Index Report. Think tanks and civil societies program, Philadelphia.
McKinsey & Company, 2009. Pathways to a Low-carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve. .
McKinsey & Company, 2010. Transformation of Europe's Power System Until Including Specific Considerations for Germany. McKinsey & Company, Dusseldorf.
Meadowcroft, J., Fiorino, D., 2017. Conceptual Innovation in Environmental Policy. The MIT Press.
Meadowcroft, J., 2009. What about the politics? Sustainable development, transition management, and long term energy transitions. Policy Sci. 42, 323–340. doi:http://dx.doi.org/10.1007/s11077-009-9097-z.
Meadowcroft, J., 2016. Let's Get This Transition Moving! Can. Public Policy 42. , pp. S10–S17. doi:http://dx.doi.org/10.3138/cpp.2015-028.
Climate Change 2001: Mitigation: Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, In: Metz, B., Davidson, O., Swart, R., Pan, J. (Eds.), 1 ed. Cambridge University Press, Cambridge; New York.
Morrison, G.M., Yeh, S., Eggert, A.R., Yang, C., Nelson, J.H., Greenblatt, J.B., Isaac, R., Jacobson, M.Z., Johnston, J., Kammen, D.M., Mileva, A., Moore, J., Roland-Holst, D., Wei, M., Weyant, J.P., Williams, J.H., Williams, R., Zapata, C.B., 2015. Comparison of low-carbon pathways for California. Clim. Change 131, 545–557. doi:http://dx.doi.org/10.1007/s10584-015-1403-5.
Moss, R.H., Nakicenovic, N., O'Neill, B.C., 2008. Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies. IPCC, Geneva.
Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., van Vuuren, D.P., Carter, T.R., Emori, S., Kainuma, M., Kram, T., Meehl, G.A., Mitchell, J.F.B., Nakićenović, N., Riahi, K., Smith, S.J., Stouffer, R.J., Thomson, A.M., Weyant, J.P., Wilbanks, T.J., 2010. The next generation of scenarios for climate change research and assessment. Nature 463, 747–757. doi:http://dx.doi.org/10.1038/nature08823.
Nakićenović, N., Lempert, R.J., Janetos, A.C., 2014. A framework for the development of new socio-economic scenarios for climate change research: introductory essay. Clim. Change 122, 351–361. doi:http://dx.doi.org/10.1007/s10584-013-0982-2.
Nakićenović, N. (Ed.), 2000. Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge; New York.
Newell, P., Mulvaney, D., 2013. The political economy of the just transition: the political economy of the just transition. Geogr. J. 179, 132–140. doi:http://dx.doi.org/10.1111/geoj.12008.
O'Neill, B.C., Kriegler, E., Riahi, K., Ebi, K.L., Hallegatte, S., Carter, T.R., Mathur, R., van Vuuren, D.P., 2014. A new scenario framework for climate change research: the concept of shared socioeconomic pathways. Clim. Change 122, 387–400. doi:http://dx.doi.org/10.1007/s10584-013-0905-2.
Organisation for Economic Co-operation and Development, 2008. Environmental Outlook to 2030. OECD Publishing Paris.
Organisation for Economic Co-operation and Development, 2009. The Economics of Climate Change Mitigation: Policies and Options for Global Action Beyond 2012. OECD Publishing Paris.
Organisation for Economic Co-operation and Development, 2012. Environmental Outlook to 2050. OECD Publishing Paris.
Oxford dictionaries, n.d. Pathway [WWW Document]. URL http://www.oxforddictionaries.com/us/definition/american_english/pathway. (Accessed 2 January 2016).
Paehlke, R., 2005. Sustainability as a bridging concept. Conserv. Biol. 19, 36–38.

Papachristos, G., 2014. Towards multi-system sociotechnical transitions: why simulate. Technol. Anal. Strateg. Manag. 26, 1037–1055. doi:http://dx.doi.org/10.1080/09537325.2014.944148.
Pielke, R.A., 2006. When scientists politicize science. Regulation 29, 28.
Pye, S., Bataille, C., 2016. Improving deep decarbonization modelling capacity for developed and developing country contexts. Clim. Policy 16, S27–S46. doi:http://dx.doi.org/10.1080/14693062.2016.1173004.
Rein, M., Schön, D., 1993. Reframing policy discourse. In: Fischer, F., Forester, J. (Eds.), The Argumentative Turn in Policy Analysis and Planning. Duke University Press, Durham, pp. 145–166.
Rogelj, J., Hare, W., Lowe, J., van Vuuren, D.P., Riahi, K., Matthews, B., Hanaoka, T., Jiang, K., Meinshausen, M., 2011. Emission pathways consistent with a 2 °C global temperature limit. Nat. Clim. Change 1, 413–418. doi:http://dx.doi.org/10.1038/nclimate1258.
Rosenbloom, D., Meadowcroft, J., 2014a. Harnessing the sun: reviewing the potential of solar photovoltaics in Canada. Renew. Sustain. Energy Rev. 40, 488–496. doi:http://dx.doi.org/10.1016/j.rser.2014.07.135.
Rosenbloom, D., Meadowcroft, J., 2014b. The journey towards decarbonization: exploring socio-technical transitions in the electricity sector in the province of Ontario (1885–2013) and potential low-carbon pathways. Energy Policy 65, 670–679. doi:http://dx.doi.org/10.1016/j.enpol.2013.09.039.
Rosenbloom, D., Berton, H., Meadowcroft, J., 2016. Framing the sun: a discursive approach to understanding multi-dimensional interactions within socio-technical transitions through the case of solar electricity in Ontario, Canada. Res. Policy 45, 1275–1290. doi:http://dx.doi.org/10.1016/j.respol.2016.03.012.
Saini, M., Shlonsky, A., 2012. Systematic Synthesis of Qualitative Research. Oxford University Press, New York.
Sanderson, B.M., O'Neill, B.C., Tebaldi, C., 2016. What would it take to achieve the Paris temperature targets?: Achieving the Paris temperature targets. Geophys. Res. Lett. 43, 7133–7142. doi:http://dx.doi.org/10.1002/2016GL069563.
Schön, D.A., 1993. Generative metaphor: a perspective on problem-setting in social policy. In: Ortony, A. (Ed.), Metaphor and Thought. Cambridge University Press, Cambridge, United Kingdom, pp. 137–163.
Scott, A.J., Storper, M., 1992. Pathways to Industrialization and Regional Development. Taylor & Francis.
Shaw, C., Nerlich, B., 2015. Metaphor as a mechanism of global climate change governance: a study of international policies, 1992–2012. Ecol. Econ. 109, 34–40. doi:http://dx.doi.org/10.1016/j.ecolecon.2014.11.001.
Shove, E., Walker, G., 2014. What is energy for? Social practice and energy demand. Theory Cult. Soc. 31, 41–58. doi:http://dx.doi.org/10.1177/0263276414536746.
Shove, E., Walker, G., Brown, S., 2014. Material culture, room temperature and the social organisation of thermal energy. J. Mater. Cult. doi:http://dx.doi.org/10.1177/1359183514525084 1359183514525084.
Shove, E., Watson, M., Spurling, N., 2015. Conceptualizing connections: energy demand, infrastructures and social practices. Eur. J. Soc. Theory 18, 274–287. doi:http://dx.doi.org/10.1177/1368431015579964.
Shove, E., 2014. Putting practice into policy: reconfiguring questions of consumption and climate change. Contemp. Soc. Sci. 9, 415–429. doi:http://dx.doi.org/10.1080/21582041.2012.692484.
Smith, A., Stirling, A., 2007. Moving outside or inside? Objectification and reflexivity in the governance of socio-technical systems. J. Environ. Policy Plan. 9, 351–373. doi:http://dx.doi.org/10.1080/15239080701622873.
Smith, A., Stirling, A., Berkhout, F., 2005. The governance of sustainable socio-technical transitions. Res. Policy 34, 1491–1510. doi:http://dx.doi.org/10.1016/j.respol.2005.07.005.
Sovacool, B.K., 2016. How long will it take? Conceptualizing the temporal dynamics of energy transitions. Energy Res. Soc. Sci. 13, 202–215. doi:http://dx.doi.org/10.1016/j.erss.2015.12.020.
Stirling, A., 2008. Opening up and closing down: power participation, and pluralism in the social appraisal of technology. Sci. Technol. Hum. Values 33, 262–294. doi:http://dx.doi.org/10.1177/0162243907311265.
Stirling, A., 2009. Direction, Distribution and Diversity! Pluralising Progress in Innovation, Sustainability and Development. STEPS Centre, Brighton.
Stirling, A., 2014. Transforming power: social science and the politics of energy choices. Energy Res. Soc. Sci. 1, 83–95. doi:http://dx.doi.org/10.1016/j.erss.2014.02.001.
Stirling, A., 2015. Emancipating transformations: from controlling the transition to culturing plural radical progress. In: Scoones, I., Leach, M., Newell, P. (Eds.), The Politics of Green Transformations. Routledge, New York, pp. 54–67.
Stone, D., 2001. Policy Paradox: The Art of Political Decision Making, 3rd ed. W. W Norton & Company, New York.
Strengers, Y., Maller, C., 2012. Materialising energy and water resources in everyday practices: insights for securing supply systems. Glob. Environ. Change 22, 754–763. doi:http://dx.doi.org/10.1016/j.gloenvcha.2012.04.004.
Swart, R., Raskin, P., Robinson, J., 2004. The problem of the future: sustainability science and scenario analysis. Glob. Environ. Change 14, 137–146. doi:http://dx.doi.org/10.1016/j.gloenvcha.2003.10.002.
Turnheim, B., Geels, F.W., 2012. Regime destabilisation as the flipside of energy transitions: lessons from the history of the British coal industry (1913–1997). Energy Policy 50, 35–49. doi:http://dx.doi.org/10.1016/j.enpol.2012.04.060.
Turnheim, B., Berkhout, F., Geels, F.W., Hof, A., McMeekin, A., Nykvist, B., van Vuuren, D.P., 2015. Evaluating sustainability transitions pathways: bridging analytical approaches to address governance challenges. Glob. Environ. Change 35, 239–253. doi:http://dx.doi.org/10.1016/j.gloenvcha.2015.08.010.
United Nations Framework Convention on Climate Change, 2015. Adoption of the Paris agreement. 21st Conference of the Parties, United Nations Paris.
Ungerstedt, U., Butcher, L.L., Butcher, S.G., Ande, N.-E., Fuxe, K., 1969. Direct chemical stimulation of dopaminergic mechanisms in the neostriatum of the rat. Brain Res. 14, 461–471.
Unruh, G.C., 2000. Understanding carbon lock-in. Energy Policy 28, 817–830.
Unruh, G.C., 2002. Escaping carbon lock-in. Energy Policy 30, 317–325.
Verbong, G.P.J., Geels, F.W., 2010. Exploring sustainability transitions in the electricity sector with socio-technical pathways. Technol. Forecast. Soc. Change 77, 1214–1221. doi:http://dx.doi.org/10.1016/j.techfore.2010.04.008.
Verhees, B., Raven, R., Kern, F., Smith, A., 2015. The role of policy in shielding, nurturing and enabling offshore wind in The Netherlands (1973–2013). Renew. Sustain. Energy Rev. 47, 816–829. doi:http://dx.doi.org/10.1016/j.rser.2015.02.036.
Walker, G., Shove, E., Brown, S., 2014. How does air conditioning become needed? A case study of routes, rationales and dynamics. Energy Res. Soc. Sci. 4, 1–9. doi:http://dx.doi.org/10.1016/j.erss.2014.08.002.
Walsh, C.L., Glendinning, S., Castán-Broto, V., Dewberry, E., Powell, M., 2015. Are wildcard events on infrastructure systems opportunities for transformational change? Futures 67, 1–10. doi:http://dx.doi.org/10.1016/j.futures.2015.01.005.
Wang, T., Watson, J., 2010. Scenario analysis of China's emissions pathways in the 21st century for low carbon transition. Energy Policy 38, 3537–3546. doi:http://dx.doi.org/10.1016/j.enpol.2010.02.031.
Wiginton, L.K., Nguyen, H.T., Pearce, J.M., 2010. Quantifying rooftop solar photovoltaic potential for regional renewable energy policy. Comput. Environ. Urban Syst. 34, 345–357. doi:http://dx.doi.org/10.1016/j.compenvurbsys.2010.01.001.
Wilson, G., 2012. Community Resilience and Environmental Transitions. Routledge.
Wise, R.M., Fazey, I., Stafford Smith, M., Park, S.E., Eakin, H.C., Archer Van Garderen, E.R.M., Campbell, B., 2014. Reconceptualising adaptation to climate change as part of pathways of change and response. Glob. Environ. Change 28, 325–336. doi:http://dx.doi.org/10.1016/j.gloenvcha.2013.12.002.
Wiseman, J., Edwards, T., Luckins, K., 2013. Post carbon pathways: a meta-analysis of 18 large-scale post carbon economy transition strategies. Environ. Innov. Soc. Transit. 8, 76–93. doi:http://dx.doi.org/10.1016/j.eist.2013.04.001.
van Vuuren, D.P., den Elzen, M.G.J., Lucas, P.L., Eickhout, B., Strengers, B.J., van Ruijven, B., Wonink, S., van Houdt, R., 2007. Stabilizing greenhouse gas concentrations at low levels: an assessment of reduction strategies and costs. Clim. Change 81, 119–159. doi:http://dx.doi.org/10.1007/s10584-006-9172-9.
van Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J.-F., Masui, T., Meinshausen, M., Nakićenović, N., Smith, S.J., Rose, S.K., 2011a. The representative concentration pathways: an overview. Clim. Change 109, 5–31. doi:http://dx.doi.org/10.1007/s10584-011-0148-z.
van Vuuren, D.P., Stehfest, E., den Elzen, M.G.J., Kram, T., van Vliet, J., Deetman, S., Isaac, M., Klein Goldewijk, K., Hof, A., Mendoza Beltran, A., Oostenrijk, R., van Ruijven, B., 2011b. RCP2. 6: exploring the possibility to keep global mean temperature increase below 2 °C. Clim. Change 109, 95–116. doi:http://dx.doi.org/10.1007/s10584-011-0152-3.
van Vuuren, D.P., Deetman, S., van Vliet, J., van den Berg, M., van Ruijven, B.J., Koelbl, B., 2013. The role of negative CO2 emissions for reaching 2 °C—insights from integrated assessment modelling. Clim. Change 118, 15–27. doi:http://dx.doi.org/10.1007/s10584-012-0680-5.
van Vuuren, D.P., Kok, M., Lucas, P.L., Prins, A.G., Alkemade, R., van den Berg, M., Bouwman, L., van der Esch, S., Jeuken, M., Kram, T., Stehfest, E., 2015. Pathways to achieve a set of ambitious global sustainability objectives by 2050: explorations using the IMAGE integrated assessment model. Technol. Forecast. Soc. Change 98, 303–323. doi:http://dx.doi.org/10.1016/j.techfore.2015.03.005.

Appendix 2

Paper 2: Framing low-carbon pathways: a discursive analysis of contending storylines surrounding the phase-out of coal-fired power in Ontario

Environmental Innovation and Societal Transitions 27 (2018) 129–145

Contents lists available at ScienceDirect

Environmental Innovation and Societal Transitions

journal homepage: www.elsevier.com/locate/eist

Original Research Paper

Framing low-carbon pathways: A discursive analysis of contending storylines surrounding the phase-out of coal-fired power in Ontario

Daniel Rosenbloom

School of Public Policy and Administration, Carleton University, 1125 Colonel By Drive, Ottawa, K1S 5B6, ON, Canada

ARTICLE INFO

Keywords:
Transitions
Discourse
Framing
Pathways
Multi-dimensional discursive approach
Coal phase-out

ABSTRACT

Transition studies have made constructive efforts to attend more closely to the politics of sustainability transitions, with discourse emerging as an increasingly important means of interrogating these dynamics. Drawing on discourse perspectives, this study deploys the multi-dimensional discursive approach to explore framing struggles surrounding a climate change mitigation experience of international significance (the phase-out of coal-fired power in Ontario), revealing how ideas, interests, institutions, and infrastructure (the four I's of sustainable energy transitions) interact in constituting pathways to sustainability. This approach captures the way in which contending actors frame issues and technologies, modulating possibilities and shaping the sequences of choices that link current societal arrangements to future low-carbon states. The study elaborates how processes of negotiation among competing interests and priorities helped define the pathway to eliminate coal. It also suggests that regulatory measures may help to accelerate the pace of transitions and succeed where market approaches are politically untenable.

1. Introduction

In the inaugural issue of this journal, Meadowcroft (2011) echoed the call to develop more politically-sensitive understandings of sustainability transitions (Meadowcroft, 2009; Shove and Walker, 2007; Smith et al., 2010, 2005; among others), pointing to the importance of interactions among *interests* (strategies and positions of political actors), *institutions* (layered norms, practices, and relations of power), and *ideas* (frames of reference that shape problem definitions and solution spaces). Since then, transition research has constructively responded to this challenge, with multiple contributions elaborating the role of ideas, interests, and institutions in shaping transformative possibilities. Of particular interest for this discussion, transition studies have begun to more deeply examine the role of discourse in: (1) framing technologies (Bosman et al., 2014; Geels and Verhees, 2011; Rosenbloom et al., 2016), (2) reinforcing or undermining institutional arrangements (Fuenfschilling and Truffer, 2016), (3) modulating the development of protected spaces for innovations (Raven et al., 2016; Smith et al., 2014), and (4) influencing the choices that define pathways to sustainability (Rosenbloom et al., 2018; Stirling, 2014). At base, discursive approaches provide additional leverage in exploring the political dimensions of transition processes, elucidating how actors frame issues and therefore shape the possibilities that might constitute transition pathways. Building on the above contributions, this paper revisits the abovementioned political domains of transitions (ideas, institutions, and interests) and engages with these factors through the *multi-dimensional discursive approach* outlined in Rosenbloom et al. (2016), extending this framework and deploying it to examine a climate change mitigation effort of international significance: the phase-out of coal-fired power in Ontario, Canada.

This study makes five main contributions to transition literature. First, a fourth interacting political domain constituting the politics of sustainable energy transitions is proposed – that is, ideas, institutions, interests, *and infrastructure* (referred to here as the

E-mail address: daniel.rosenbloom@carleton.ca.

https://doi.org/10.1016/j.eist.2017.11.003
Received 11 May 2017; Received in revised form 26 November 2017; Accepted 27 November 2017
Available online 28 November 2017

four I's of sustainable energy transitions). Second, analytical refinements to the multi-dimensional discursive approach are offered in order to more explicitly embrace the four I's and *the implications storylines suggest for unfolding pathways*. Here I adopt the socio-technical conception of "pathways", which takes this concept to mean "the unfolding socio-technical patterns of change within societal systems as they move to meet human needs in a low-carbon fashion" (Rosenbloom, 2017, p. 39). Third, the analysis elucidates the framing struggles surrounding the pathway adopted to phase-out coal-fired power in Ontario, which has been called the "single largest GHG emissions reduction action on the continent" and resulted in an annual reduction of roughly 33 Mt of CO2eq (Ontario Ministry of Energy, 2015, p. 3). Not only does this represent a major GHG reduction effort, it is also an instance where a regulatory rather than market-based approach helped promote the journey to decarbonize energy systems. Shedding light on these dynamics is of particular relevance as international jurisdictions (e.g., Denmark, Britain, Finland, Germany, and others) embark upon similar initiatives. Fourth, while the climate-related priorities of Ontario's coal phase-out have been called into question (McKitrick, 2017; McKitrick and Aliakbari, 2017), this study demonstrates that this initiative was motivated and shaped by complex and evolving considerations that were rooted in regional air quality issues but also inextricably entwined with climate change concerns. Indeed, the analysis finds that continual struggles among contending interests and priorities helped define the pathway to phase-out coal. Finally, more general discursive patterns are identified which mark framing struggles around sustainability transitions, explaining these dynamics in terms of discursive resonance (i.e., the strength and alignment of components constituting storylines).

The argument in this paper unfolds in the following steps. The analysis begins by detailing the multi-dimensional discursive approach, proposed extensions, and specific methodological choices. Subsequently, the discursive dynamics surrounding the elimination of coal in Ontario are examined, revealing several contending storylines. The paper concludes by reflecting on the identified discursive patterns and their implications for transitions theory and practice.

2. Approach

Over the past several years, discourse has emerged as an increasingly important approach to elucidate the political dimensions of sustainability transitions (e.g., Bosman et al., 2014; Geels and Verhees, 2011; Munoz et al., 2014; Raven et al., 2016; Roberts, 2017; Rosenbloom et al., 2016; Teschner and Paavola, 2013). While discourse-transition crossovers are founded upon a variety of theoretical foundations (e.g., Fischer and Forester, 1993; Hajer, 1995; Schmidt, 2008), they have a fundamental, albeit often implicit, interest in scrutinizing the four interacting political domains of socio-technical transitions, weaving connections among ideas (as reflected by narratives and frames of reference), institutions (as reflected by rule systems), interests (as reflected by strategies and positions of political actors), and infrastructure (as reflected by material systems; see Fig. 1). Teschner and Paavola (2013, p. 449), for instance, submit that ideas "frame and constrain what can be perceived as possible solutions to societal problems" and "alongside infrastructural networks and vested interests, can help [explain] lock-in". Framing, in this view, is not only about making sense of complex realities but also relates to important strategic functions as actors actively structure policy issues in such a fashion as to privilege particular solutions and interests (Rein and Schön, 1993; Stone, 2001). Fuenfschilling and Truffer (2016, pp. 299–300), similarly, elaborate how actors work "to construct meaning, beliefs, rules or standards and thereby shape the course of institutional change", with discourse underpinning much of this "institutional work". Still others explicate the way in which actor networks struggle over the legitimacy of particular technological arrangements (e.g., nuclear energy facilities) and their associated socio-

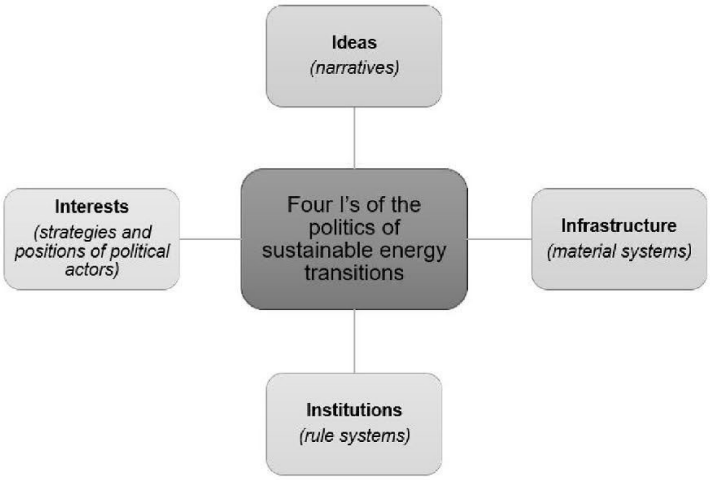


Fig. 1. The interacting political domains of sustainable energy transitions.
This figure depicts the four interacting domains that constitute the politics of sustainable energy transitions. Prominent ways these domains manifest are presented in parentheses, reflecting possible points of access for analysts to gain traction on the four I's.

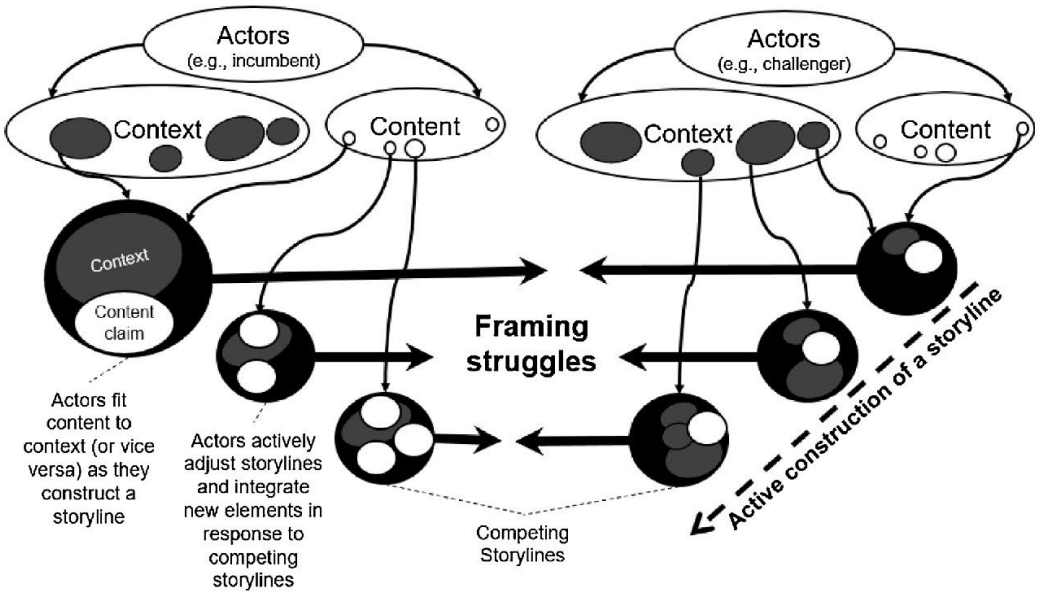


Fig. 3. Processes of multi-dimensional discursive interaction.
This figure is drawn from Rosenbloom et al. (2016).

the alignment of components constituting a storyline (i.e., content, context, and actors). That is, successful storylines are characterized by strong alignments among compelling content-related claims, relevant contextual developments, and credible messengers.

This study applies the abovementioned framework to explore the discursive interactions surrounding the coal phase-out in Ontario, Canada. Three research questions orient the study: (1) what are the prominent storylines surrounding the coal phase-out; (2) how did these storylines mature and interact over time; and, (3) what implications might these storylines have presented for the pathway to eliminate coal-fired power? That is, the primary focus of this analysis is to shed light on the interacting political domains of sustainable energy transitions (ideas, institutions, interests, and infrastructure) by exploring *storylines* and their *constituting components* (actors, content, and context). Here the paper deviates somewhat from more traditional discursive analyses (e.g., Hajer, 2006) that emphasize other factors (e.g., discourse coalitions).

To answer the abovementioned research questions, an analysis of media articles was conducted. Sources were selected based on a keyword search ("Ontario" AND "coal phase out" OR "phase out coal") of newspaper articles in the ProQuest Canadian Newsstream database – one of the largest full-text databases of historical newspaper articles for both major (e.g., the Toronto Star and Globe and Mail) and regional (e.g., the St. Catharines Standard and Sarnia Observer) media sources in Canada. The relevant temporal scope was determined to span from 1998 to the achievement of the coal phase-out in 2014. This search yielded a total sample of 345 newspaper articles after eliminating false positives and duplicates.

A three-stage process was employed to analyze these sources. First, an in-depth review of the 345 articles was carried out to identify emergent themes and categories (i.e., storylines and their constituting components) as well as the phases marking the framing struggles around coal-fired power in Ontario (e.g., key political battles spanning provincial elections). Second, sources were revisited to refine the previously identified themes, categories, and phases. Combining elements of thematic and content analysis (Dixon-Woods et al., 2005), the identification of prominent storylines and their constituting components (content, context, and actors) was carried out in an iterative and inductive fashion that permitted for the ongoing reconsideration of themes and categories. Finally, a third review was conducted to assess the article-level (as opposed to sentence or paragraph-level) frequency of storylines. This entailed revisiting articles to record instances of specific narratives contributing to each storyline, counting only distinct storylines once per article. This choice was made to avoid overweighting individual articles (or authors) as some sources contained several instances of specific narratives invoking a single storyline. In this fashion, the aim was to capture the evolving frequency of storylines *across* articles rather than *within* articles as this was considered to be a more accurate metric of the way in which a broad array of societal actors struggled to frame coal over the course of its phase-out in Ontario.

Additional steps were taken to supplement and crosscheck the discursive analysis. First, a broader examination of secondary sources (e.g., reports and academic articles) and power sector data (e.g., changes in installed electricity capacity) was carried out to trace the relevant historical dynamics surrounding the pathway to phase-out coal. Second, the results of the discursive analysis were exposed to expert opinion at the 2017 Ontario Network for Sustainable Energy Policy workshop. Nevertheless, there remain some

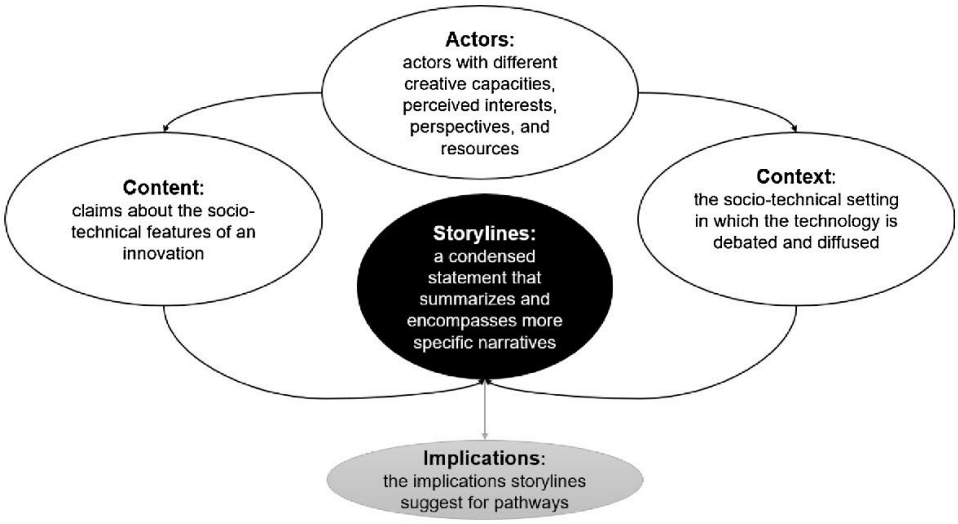


Fig. 2. The multi-dimensional discursive approach to storyline formation.
This figure is adapted from Rosenbloom et al. (2016). *Extensions are presented in grey.*

technical possibilities in order to influence the course of innovation journeys (Geels and Verhees, 2011). Thus, discourse has important implications for transition processes as actors strategically leverage ideas to frame issues and technologies in order to privilege certain courses of action, thereby maintaining or disrupting socio-technical system configurations and constituting unfolding pathways to sustainability.

Drawing together these perspectives, this paper adapts and deploys the multi-dimensional discursive approach outlined in Rosenbloom et al. (2016). This approach captures: (1) the way in which contending actors struggle to frame technologies using narrative work in the context of outward-oriented policy debate; and (2) the process by which narratives are iteratively developed through the ideational capacity of actors (their resources, creativity, and perceived interests) to link content-related and contextual claims in order to frame a technology in a certain way and suggest a particular course of action (see Fig. 2). From this, three units of analysis are of particular interest: (i) *actors* who behave in a fashion that advances their perceived interests; (ii) the *content* or socio-technical characteristics of a specific technology; and (iii) the *context* in which the technology is debated, developed, and diffused. Here, a fourth unit of analysis is proposed: (iv) the *implications* suggested by storylines for pathways. This extension aims to more explicitly embrace the way in which storylines frame problems, modulate possibilities, and therefore shape the sequences of choices and consequences that link current societal arrangements to future low-carbon states (Rosenbloom et al., 2018). Moreover, these units of analysis encompass the four I's of sustainable energy transitions, revealing how interests (strategies and positions of political actors), ideas (storylines), institutions (context), and infrastructure (content but also context) interact in defining pathways (through the implicit and explicit implications of storylines). Taken together, this approach elucidates processes of discursive interaction among contending actors and demonstrates how agents, based on their perceived interests, selectively make claims about the socio-technical characteristics of a technology (e.g., technical efficiency, environmental impact, employment potential) and fit these claims to a specific context (e.g., institutional commitments, infrastructure investments, and issues facing the relevant societal system) in order to develop storylines that frame the issue and technology in a particular way. Importantly, these framing struggles are understood as continually evolving as actors actively respond to competing storylines (see Fig. 3).

The *discursive resonance* of a storyline (i.e., the extent to which a storyline gains traction among policymakers and the public) can be understood in terms of (1) the strength of the components constituting the storyline and (2) the degree of alignment among these elements. Adapting the work of Snow and Benford (2000, 1992) as well as Geels and Verhees (2011), the strength of storyline components relates to the believability of claims, the centrality of the issue, and the credibility of the messenger(s). The former concerns the correspondence between content-related claims (e.g., coal is dirty or solar creates jobs) and perceptions about the real world or proximate experiences (Snow and Benford, 1992). This is not a measure of objective accuracy but rather reflects a general sense of believability based on the perceived adherence between claims and what is considered to constitute evidence (i.e., some element of the world that can be pointed to as evidence of the embedded claim), accounting for the 'post-truth' character of recent policy debates (Walton-Roberts et al., 2014). The centrality of the issue relates to the perceived importance of the topic or debate (Geels and Verhees, 2011). Storylines that make relevant links to urgent contextual developments (e.g., pressing economic, health, or environmental issues) are likely to gain greater traction (Kingdon, 1984), though issues will continually rise and fall within the public consciousness (Downs, 1972). The appeal of a storyline is also linked to the perceived credibility of the actor transmitting it (Benford and Snow, 2000), which may differ across constituencies depending on worldviews. Beyond this, discursive resonance also involves

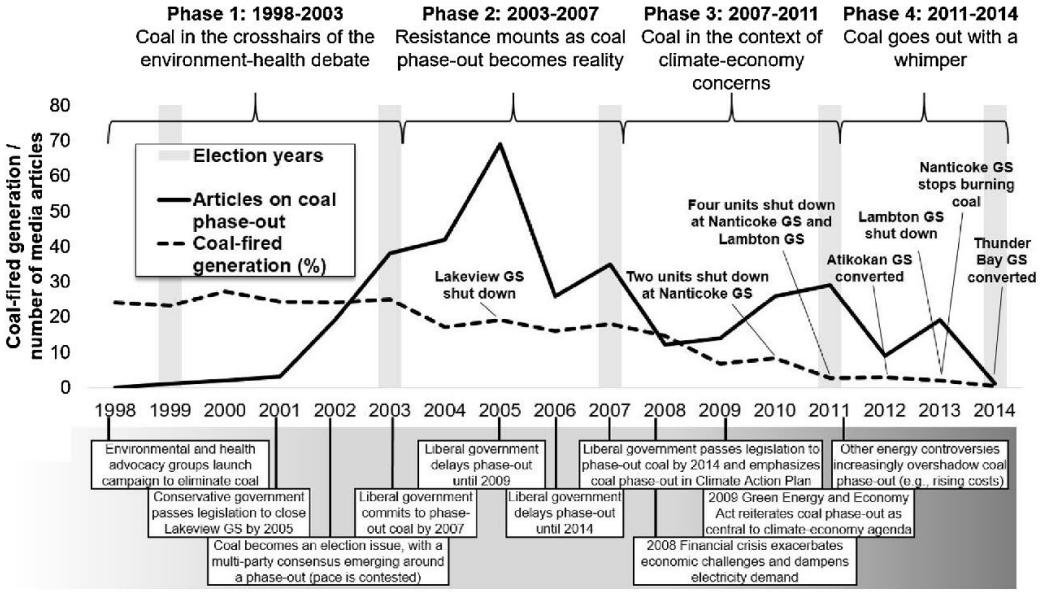


Fig. 4. Key phases and developments marking the pathway to eliminate coal-fired power.
The phases identified reflect: (1) the evolving discursive dynamics captured by the analysis of 345 media articles, (2) provincial election cycles, (3) the declining share of electricity supplied by coal-fired generating stations (GS) in Ontario as these assets were retired or converted to burn biomass, and (4) unfolding political and socio-institutional developments.

limitations in carrying out a discursive analysis of media articles. For instance, the more covert avenues through which actors may have been constituting and conveying narratives (e.g., as part of backroom lobbying) may not be adequately represented. Still, a focus on the media is warranted as it plays a dual role in both reflecting and shaping discourse and perceptions regarding technologies and policy (Delshad and Raymond, 2013; Mallett et al., 2017).

3. Discursive interactions surrounding the coal phase-out in Ontario

While the pathway to phase-out coal in Ontario is characterized by a variety of complex patterns, it is not the objective of this study to provide an in-depth reconstruction of these events as this has largely been addressed elsewhere (Harris et al., 2015; Rosenbloom and Meadowcroft, 2014; Winfield, 2017, 2012). Rather, the aim here is to 'zoom in' on the discursive dynamics unfolding during key phases of contestation marking this pathway (see Fig. 4) and in so doing shed light on the interconnected political domains of sustainable energy transitions (interests, ideas, institutions, and infrastructure) insofar as they are manifest in discursive interactions.

As illustrated in Fig. 4, the analysis identifies four key phases of contestation that mark the pathway to eliminate coal-fired power in the province. These phases reflect: (1) the evolving discursive dynamics captured by the analysis of 345 media articles, (2) provincial election cycles, (3) the declining share of coal in the province's electricity mix, along with (4) unfolding political and socio-institutional developments. Roughly spanning election years, the phases detail how discursive interactions around coal moved from health-environment controversies, to concerns around the reliable and efficient operation of the electricity system, to the rollout of a climate-economy agenda, and finally to relative obscurity. During these phases, the discourse can be categorized in terms of six contending storylines, which framed coal-fired power as either: *a public health crisis* (Delegitimizing storyline 1 or D1 in Table 1); *a drain on the economy* (D2 in Table 1); *a climate change problem* (D3 in Table 1); *an accepted and common component of electricity systems* (legitimizing storyline 1 or L1 in Table 1); *part of a reliable and affordable electricity system* (L2 in Table 1); or *'not so bad'* (L3 in Table 1).

Although all six storylines reflect a series of interesting framing struggles, this study focuses on the interactions among the three most prominent storylines (D1, D3, and L2; see Fig. 5), the constituting components of these storylines (actors, content, and context), as well as their maturation over the identified phases. In general, D1 gained traction in the first phase, built momentum in the second phase, and held a strong position relative to other storylines in later phases. In contrast, D3 acquired greater prominence during the final two phases. Responding to delegitimizing storylines, the prevalence of L2 was most notable in the second phase. Other storylines played a somewhat lesser role in the framing struggles surrounding the decline of coal. Prior to interrogating these discursive dynamics in greater detail however, a brief overview of the electricity system in Ontario is needed to help situate discursive interactions surrounding the coal phase-out.

Table 1
Contending storylines surrounding the coal phase-out.

Delegitimizing storylines	Illustrative narratives invoking storylines		Legitimizing storylines
D1: Coal-fired power as a public health crisis	*Coal-fired power is an outmoded and dirty way to generate power which impacts human health through reduced air quality, killing thousands annually*	*As Ontario's electricity system is highly interconnected and coal is a prevalent source of power across the region, it is not possible to move away from coal*	L1: Coal-fired power as an accepted and unavoidable component of modern electricity systems
D2: Coal-fired power as a drain on the economy	*Coal-fired power is reducing productivity and costing billions in additional health-related expenditures every year*	*Without coal, Ontario's power system would face severe reliability issues and rising costs*	**L2: Coal-fired power as part of a reliable and affordable electricity system**
D3: Coal-fired power as a climate change problem	*Coal-fired power is a major source of GHG emissions and its continued use is inconsistent with climate commitments*	*The environmental and health impacts of coal-fired power are limited and can be ameliorated through clean coal solutions*	L3: Coal-fired power as 'not so bad'

The three most prominent storylines are presented in bold.

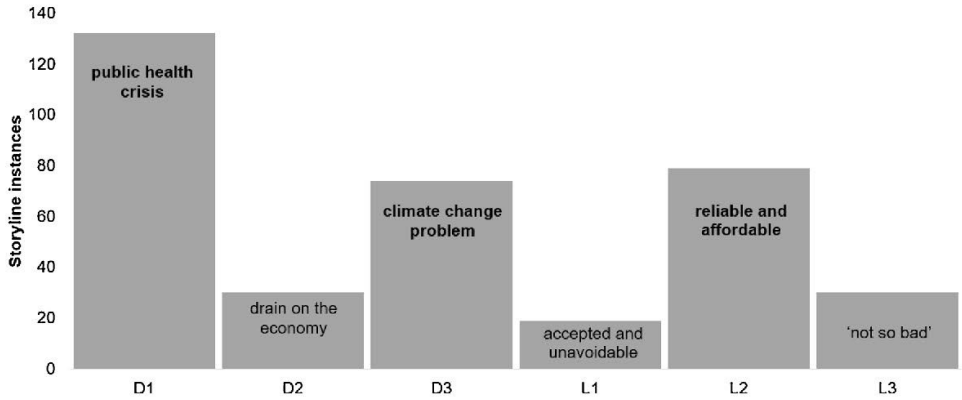


Fig. 5. Storyline instances from 1998 to 2014.
This figure displays the results of the discursive analysis of 345 newspaper articles. It depicts article-level instances of each storyline from 1998 to 2014. Delegitimizing storyline 1 (D1), delegitimizing storyline 3 (D3), and legitimizing storyline 2 (L2) represent the most prominent storylines.

At the outset of the coal phase-out debate in the late 1990s, electricity generation in the province of Ontario was principally based on nuclear (~40%), hydroelectric (~25%), and coal-fired (~25%) sources. This system configuration was secured under an expansionist orientation led by Ontario Hydro, the publicly-owned and operated utility (Rosenbloom and Meadowcroft, 2014). Under this orientation, energy consumption and extensive investments in grid infrastructure were promoted as part of a virtuous cycle benefitting key political and economic interests. Hydroelectric facilities were largely deployed in the first half of the twentieth century, but resource endowments were outpaced by demand as electric appliances and industrial applications diffused widely over the ensuing decades (McKay, 1983). To meet rising electricity demand, coal-fired assets – most prominently, Atikokan, Nanticoke, Lambton, Lakeview, and Thunder Bay generating stations – were built out in the 1960s and 70s. In the 1970s and 80s, attention shifted to nuclear energy, with substantial expenditures in Pickering, Bruce, and Darlington nuclear stations. By the late 1990s, the expansionist orientation driving the development of the electricity system was facing severe internal issues (e.g., the mismanagement of the nuclear energy file) along with external pressures (e.g., stagnating electricity demand and the rise of neoliberalism among policymakers). Moreover, a highly damaging performance assessment was released in 1997 that prompted the temporary shutdown of several nuclear reactors and an increasing reliance on coal capacity (Jackson and de la Mothe, 2001). These problems culminated in financial issues for Ontario Hydro, a crisis of legitimacy for the public utility, and rising electricity prices that opened a window of opportunity for the Conservative government to restructure the system in 1998 (Ontario Hydro was broken up into several operational units) and pave the way for a liberalized electricity market, though this would not fully materialize (Swift and Stewart, 2004).

3.1. 1998–October 2003: coal in the crosshairs of the environment-health debate

As environmental and health concerns mounted among the public in the late 1990s (Rowlands, 2007; Winfield, 2012), the growing reliance on coal became increasingly contentious. In light of this, environmental and health advocacy groups (e.g., the Ontario Clean Air Alliance and the Ontario Medical Association) launched campaigns to highlight the impacts of coal-fired power on human health and the environment. A report by the Ontario Medical Association (1998), in particular, explicated the links between coal, environmental issues (air quality), and public health (premature deaths). This report was instrumental in providing a credible evidence base from which to advocate the phase-out of coal-fired power. The prevalence of smog days in the region helped to further

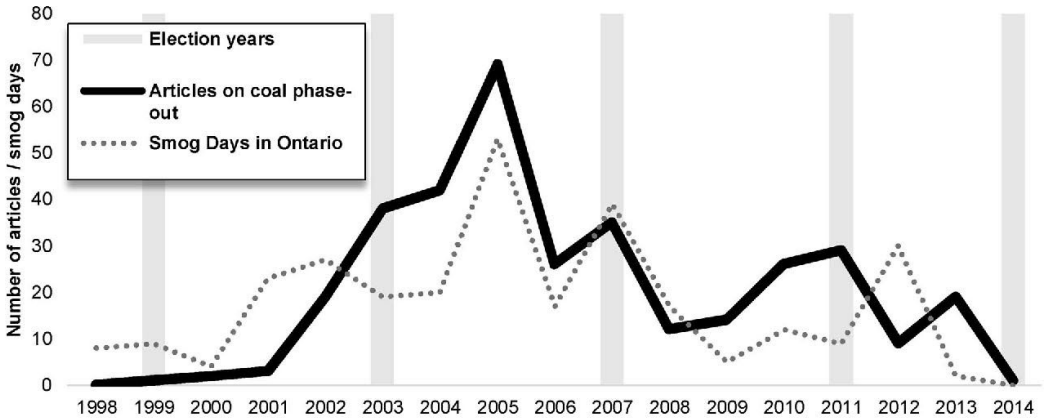


Fig. 6. Smog days and media coverage of the coal phase-out in Ontario.
This figure presents the number of smog days in Ontario and the sample of 345 media articles analyzed, pointing to the close relationship between the coal phase-out debate and regional health-environment issues.

crystallize environment-health linkages for the public and the media (see Fig. 6). Internationally and domestically, climate concerns were also beginning to mount with the signing of the Koto Protocol in 1997. In response to these developments, the Conservative administration appointed an all-party Select Committee on Alternative Fuel Sources in 2001 "to investigate, report and recommend ways of supporting the development and application of environmentally sustainable alternatives to our existing fossil (carbon-based) fuel sources" (Legislative Assembly of Ontario, 2002, p. 1). Shortly after, legislation was passed to close the Lakeview station near Toronto by 2005. In 2002, the committee recommended replacing coal-fired sources by 2015 through a combination of natural gas, renewables, and conservation.

And while earlier provincial elections featured some debate around coal (e.g., the 1999 Liberal platform vowed to convert coal-fired power plants to natural gas), the coal problem became an increasingly prominent issue in the run-up to the 2003 election. All three major political parties staked out positions, with a consensus emerging around the elimination of coal. However, there was still much disagreement about the pace of this reconfiguration and how exactly it might be achieved (converting the coal units to natural gas versus investing in new generating assets). The Conservatives targeted 2015, whereas the Liberals and New Democrats proposed a much more rapid deadline of 2007 (Harris et al., 2015).

3.1.1. Discursive dynamics

The analysis of discursive patterns indicates that the most prominent storyline advanced during this phase appealed to rising health-environment concerns, framing coal as a public health crisis (see Figs. 7 and 8). Invoking this storyline, health-environment advocates (but also municipal officials in Southwestern Ontario and political parties critical of the governing Conservatives)

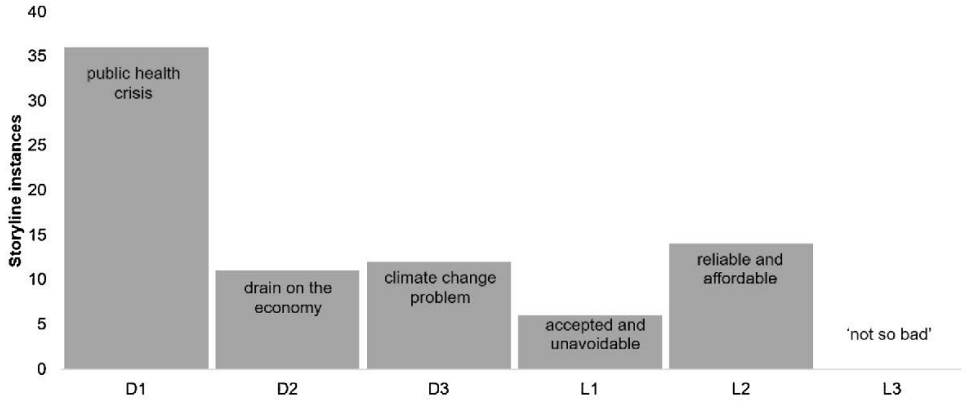


Fig. 7. Storyline instances (1998–October 2003).
This figure displays the results of a discursive analysis of 53 newspaper articles surrounding the coal phase-out during this period. It indicates that the storyline depicting coal-fired power as a public health crisis was most prominent at this time.

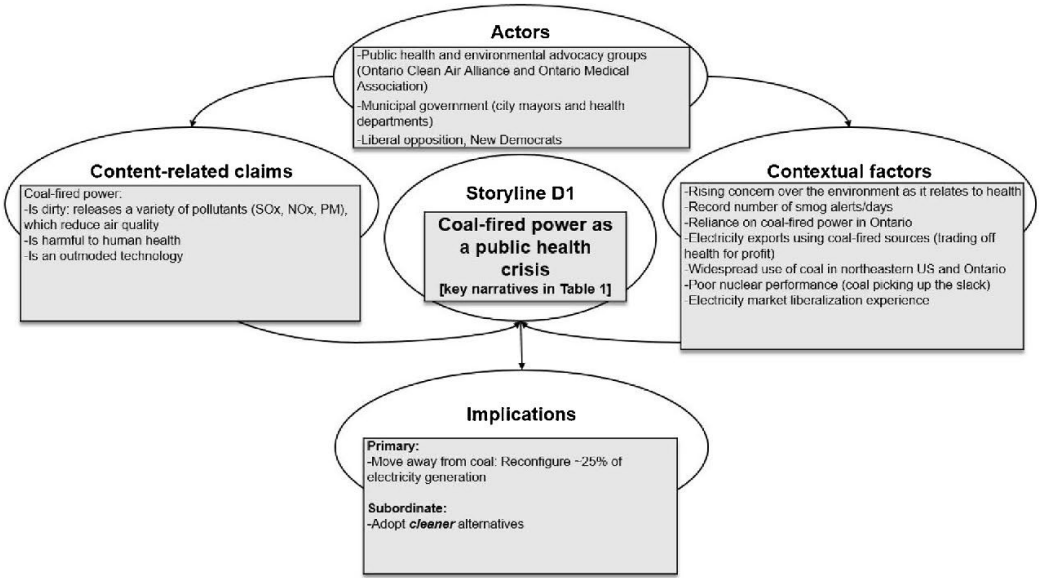


Fig. 8. Constituting components of storyline D1.
This figure shows how actors selectively wed content-related claims to context in order to craft specific narratives contributing to a storyline that frames coal-fired power as a public health crisis.

developed specific narratives that made selective content-related claims about the contribution of coal units to smog-related air pollutants and married these claims to relevant contextual factors such as the record number of smog days in the region. As part of this delegtimizing storyline, actors also linked claims about coal-fired power to problems in the electricity system such as declining environmental performance and electricity export practices that could be perceived as trading off public health for revenue (Elston, 2002). As summarized in Fig. 8, actors advanced narratives that brought together content and context in such a fashion as to portray coal-fired power as an outmoded and dirty source of power, with serious impacts on human health. This storyline aimed to solidify the causal story of coal as a major contributor to regional health-environment issues. In this way, coal, rather than the multitude of complex causal factors associated with poor air quality, was cast as the villain. The implication of this delegitimizing storyline was to eliminate coal-fired power as rapidly as possible through the reconfiguration of roughly 25% of electricity generation in the province. Indeed, according to health-environment advocates, "[t]he bottom line is simple: [c]oal power is costing us the air we breathe and it has to go" (Gibbons, 2000). In the leadup to the 2003 election, this storyline was taken up by the political opposition, with Dalton McGuinty, leader of the Liberal Party, stating that "[c]oal is 19th century, it's dirty, it's dangerous" (Lindgren, 2002).

While far less prominent than health-related narratives, actors also developed specific narratives invoking a climate-related storyline. As part of this, actors drew together content-related claims about the carbon-intensity of coal-fired power and placed this in the context of more ambitious climate commitments (e.g., the Kyoto Protocol) in order to paint coal as a climate change problem. The Ontario Public Health Association, for instance, stated that "Ontario's coal-fired power plants emitted 35 million tonnes of carbon dioxide last year – that is 78 per cent of the greenhouse gases that Ontario would need to cut in order to fulfil the reductions envisioned by the Kyoto Protocol", adding that "[w]hile we are concerned about all four environmental issues associated with coal-fired power plants, climate change drives our call for their phase-out"[1]; (Lee and Perrotta, 2002). Rather than solely advocating for the uptake of 'cleaner' sources (i.e., natural gas), this storyline implied the replacement of coal-fired units with low-carbon energy technologies.

Another set of narratives contributed to a storyline depicting coal-fired power as a drain on the economy. As part of this, actors claimed that coal reduced Ontario's competitive position (e.g., it resulted in productivity losses due to poor air quality and additional health care costs) and linked this to ongoing competitiveness concerns around globalization. A number of narratives invoking this storyline pointed to the modelling work of the Ontario Medical Association, which estimated the significant negative externalities of coal. This storyline called into question the economic benefits of coal-fired power, suggesting that there would be considerable cost-savings from the closure of coal units.

In marked contrast to the formation of delegitimizing storylines, the analysis suggests that actors supporting the continued use of coal were less organized during this early phase of discursive interaction. Perhaps due to the abovementioned restructuring process

[1] The four environmental issues the authors refer to are climate change, smog, acid rain, and mercury.

(the provincial electricity utility was broken up at the end of the 20th century and the sector was being prepared for market liberalization), actors involved in the operation of the electricity system were less engaged in this debate. Nevertheless, think tanks (e.g., Energy Probe), unions (e.g., Power Workers' Union), and the new operational units of the now-defunct Ontario Hydro (e.g., Ontario Power Generation who now owned and operated the coal plants) began to develop specific narratives contributing to two main storylines that attempted to counter calls for a phase-out. The most common legitimizing storyline painted coal as an important part of a reliable and affordable electricity system. Even though this storyline acknowledged the environmental impacts of coal, it emphasized the reliable and competitive features of this power source. These content-related claims were linked to unfolding contextual developments, including the 2003 northeast blackout and California energy crisis, asserting that rising costs and brownouts would become commonplace if coal were no longer part of the electricity mix. At base, this storyline implied that the continued use of coal was a prudent choice that would avoid economic and reliability problems. Interestingly, while there appeared to be support for a coal phase-out among the governing Conservatives, this storyline was taken up by key members of the party. The Conservative energy minister, for instance, stated on more than one occasion that without coal, reliability would become a serious problem (e.g., Lindgren, 2002), perhaps echoing the reservations of interests in the electricity sector.

Actors aligned with the established electricity configuration also advanced a storyline which framed coal-fired power as an accepted and unavoidable component of modern electricity systems, linking the competitive features of coal to its prevalence in neighboring jurisdictions. Sharing similarities with carbon leakage arguments, this storyline presented coal-fired power as inescapable in the context of interconnected electricity markets as shutting down domestic coal plants would mean ramping up generation from coal facilities in other jurisdictions. This storyline suggested that, although it might be appropriate to phase-out coal in the long-run (in concert with other jurisdictions), this capacity should be maintained given the realities of existing electricity systems.

3.2. October 2003–October 2007: resistance mounts as coal phase-out becomes reality

In October 2003, the Liberals swept to power and formed a majority government that allowed them to put the coal phase-out into motion. As election promises began to translate into concrete action, the Liberal government moved to procure alternative electricity sources (natural gas but also emerging renewables), bring laid up nuclear reactors back online at Pickering and Bruce stations, and promote conservation (Fig. 9). In essence, the phase-out entailed billions of dollars in grid infrastructure spending in order to displace the publicly-owned legacy coal units making up roughly 20% of electricity generation at the time. Confronted with a dysfunctional electricity market introduced but then quickly abandoned by the previous Conservative government in 2002, the Liberals reinstated central planning powers over electricity procurement through the establishment of a planning authority tasked with developing long-term system plans and managing government-directed power purchase agreements for new supply. In this fashion, a hybrid system emerged, which meshed central planning functions with preferences for private investment (Rosenbloom and Meadowcroft, 2014).

Despite the limited coal interests in Ontario (most of the coal was sourced from the United States and western provinces), actors mobilized and challenged the coal phase-out (Rosenbloom and Meadowcroft, 2014). These actors included think tanks (e.g., Fraser Institute and Energy Probe), labor unions (e.g., the Power Workers' Union), industry associations (e.g., Association of Major Power Consumers of Ontario), and communities where coal plants were sited (e.g., Haldimand County). Ontario Power Generation also made efforts to reassert the importance of coal-fired power, but this organization was largely beholden to the priorities of the government as its shareholder.

Yielding to this resistance, the Liberal administration began to reassess the timeline for the phase-out. In the summer of 2005, the Liberals extended the 2007 deadline to 2009 in light of insufficient investment in new supply and rising peak power consumption – 9

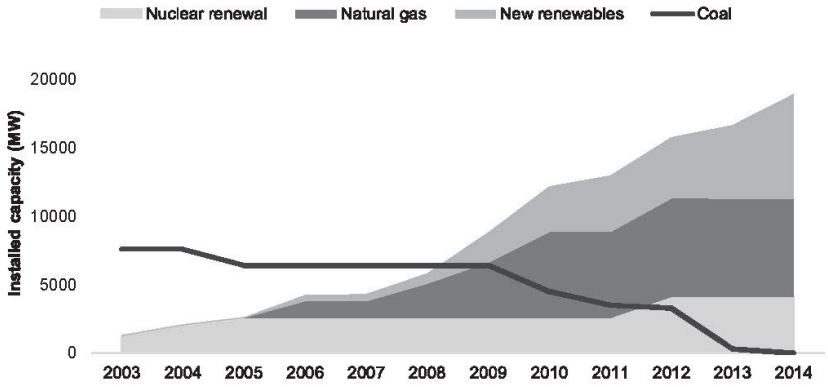


Fig. 9. New electricity capacity procurement and the decline of coal.
This figure displays the diminishing role of coal-fired electricity capacity as new sources (natural gas, nuclear restarts at Bruce station, and emerging renewables) were brought online. Data for this figure are drawn from the Independent Electricity System Operator's progress reports on contracted electricity supply.

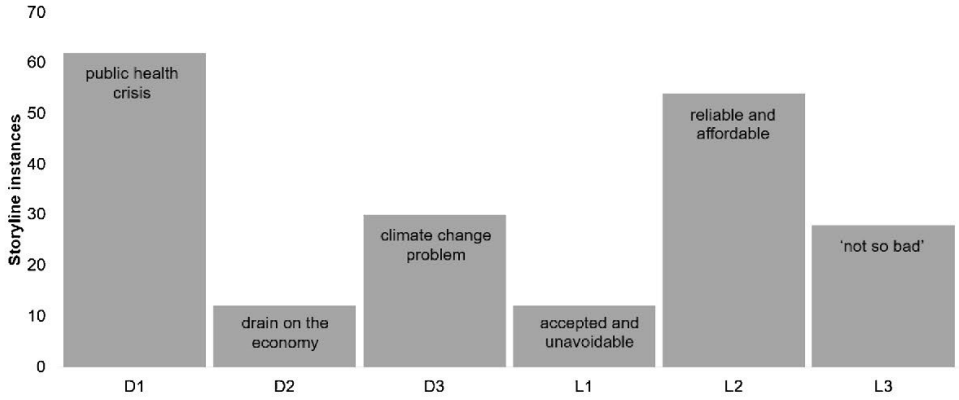


Fig. 10. Storyline instances (October 2003–October 2007).
This figure displays the results of a discursive analysis of 179 newspaper articles surrounding the coal phase-out during this period. It indicates that the storyline depicting coal-fired power as part of a reliable and affordable electricity system acquired increasing prominence at this time.

of the top 20 record demand days in the last 15 years occurred in 2005 (Independent Electricity System Operator, 2017). Unexpectedly, proponents of the coal phase-out (e.g., the Ontario Clean Air Alliance) were relatively supportive of the delay, acknowledging the ambitious nature of the task. However, in the fall of 2006, the Liberals again delayed the target date to 2014, citing reliability issues (Cundiff, 2015). In contrast to the earlier delay, this attracted more forceful demands to accelerate the pacing of the phase-out. The above battles continued to play out during the leadup to the 2007 elections. And, in the summer of 2007, the Liberal government passed legislation that enshrined the 2014 deadline (Ontario Ministry of Energy, 2015). At the same time, the climate credentials of the coal phase-out were emphasized in the province's first climate action plan (Ministry of the Environment and Climate Change, 2007). Interestingly, the Conservatives began to back away from their commitment to phase-out coal by 2015, intimating that they would instead install scrubbers on coal units and only replace them when practicable (McCarthy, 2007).

3.2.1. Discursive dynamics

The discursive analysis indicates that this phase is marked by the most intense episode of political contestation surrounding the elimination of coal in Ontario. While proponents of the coal phase-out continued to advance a series of narratives invoking storylines that delegitimized coal-fired power, competing actors engaged in more extensive efforts to legitimize the place of this electricity source in Ontario's energy future (see Fig. 10). During this time, the character of storylines delegitimizing coal remained largely similar. In the face of strong health-environment concerns and frequent smog alerts, the health crisis storyline appeared most frequently. However, as specific narratives were adapted, they began to reveal internal tensions among proponents, particularly with respect to the role of nuclear in displacing coal. On the one hand, health-environment advocates fit content-related claims about coal to unfolding contextual developments involving delays in restarting laid up nuclear reactors, contending that "[f]urther reliance on nuclear power could jeopardize Ontario's coal phase-out and leave us with steadily growing air-quality problems" (Gibbons, 2004). In this view, poor nuclear reactor performance was the reason that Ontario had to ramp up coal use in the first place. The governing Liberals, on the other hand, continued to advance health-related narratives, but did not draw on nuclear performance issues as the administration was entertaining nuclear renewal as a potential option to eliminate coal (Toronto Star, 2005).

In marked contrast to the first phase, the analysis shows that storylines legitimizing coal acquired greater prominence during this period (as illustrated in Fig. 10). A wide-ranging network of actors mobilized to advance narratives about the importance of coal for the electricity system in the province. Of these narratives, the most common revolved around reliability and affordability (see Fig. 11). Major power consumers, labor unions, and actors involved in the operation of the electricity system, among many others, leveraged their resources to link the competitive and reliable features of coal to projected increases in electricity demand and ongoing concerns about grid infrastructure in order to frame coal as central to an affordable and reliable electricity system. The Fraser Institute, for instance, stated that "closing the coal-fired plants will imperil industrial development in Ontario, increase energy costs, and reduce the reliability of the electricity supply" (Standard, 2005). Similarly, the Power Workers' Union contended that "[c]oal is the insurance Ontario will have reliable, reasonably priced electricity today and tomorrow" (Stephenson, 2005). Rather than replacing the coal-fired plants, the implication here was to maintain this capacity for either the long-run or until alternative energy sources could be brought online at a reasonable cost. Some also advocated installing scrubbers on the plants to address immediate health concerns, likely securing their place in the electricity mix for the long-term. The reliability and affordability storyline resonated with the public and decision-makers as the governing Liberals began to moderate their phase-out aspirations. Indeed, in justifying the need to delay the coal phase-out until 2014, Premier McGuinty submitted that "[w]e've always got to reconcile our eagerness to eliminate coal-fired generation with our responsibility to maintain a reliable supply of affordable electricity" (Howlett, 2006). In this fashion, even proponents of the phase-out began to display concerns about the pace and scale of change required now that implementation was underway.

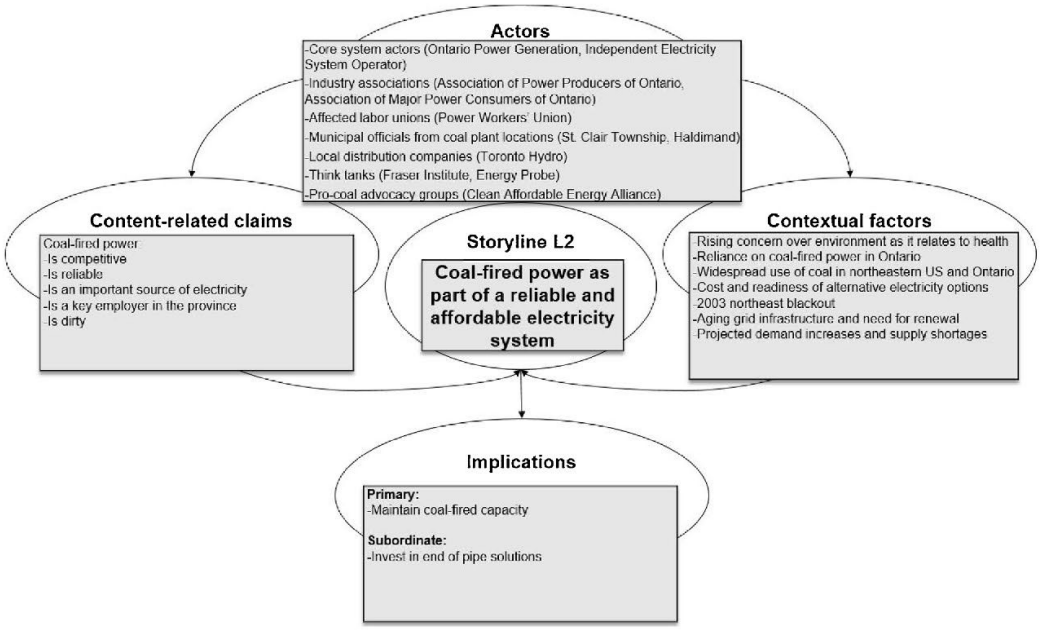


Fig. 11. Constituting components of storyline L2.
This figure shows how actors selectively wed content-related claims to context in order to craft specific narratives contributing to a storyline that frames coal-fired power as part of a reliable and affordable electricity system.

During this time, actors also developed narratives contributing to somewhat less prominent legitimizing storylines. Invoking a storyline depicting coal-fired power as accepted and unavoidable, the Millwright and Machine Erectors Union argued that "[t]he only alternative is to buy more power from the United States, who use even more coal" (Lafleche, 2005). Another storyline also emerged, which attempted to downplay the overall impact of coal on health and the climate, framing coal as 'not so bad'. Narratives invoking this storyline attempted to undermine the closure of Ontario's coal plants by trivializing its merits, making content-related claims about the pollution from coal units but wedding these negative claims to contextual factors surrounding the many other contributors to smog and GHG emissions. Responding to health-related narratives painting coal as a major contributor to air pollution, coal supporters suggested that "Ontario's coal plants combined account for only six per cent of the province's pollution"[2] (McCaffery, 2005). As part of this, some coal advocates pointed to clean coal solutions (e.g., scrubbers and carbon capture and sequestration) as a way to extend the role of this power source.

3.3. October 2007–October 2011: coal in the context of climate-economy concerns

In October 2007, the Liberals were re-elected with a majority government and carried on with the implementation of the coal phase-out. Although political battles over the phase-out continued, attention began to shift to economic challenges exacerbated by the 2008 global financial crisis (Winfield, 2012). Responding to rising economic and climate concerns, the Liberal government introduced the Green Energy and Green Economy Act in 2009 (with the Feed-in Tariff for new renewables as its centerpiece program). At the same time, the economic downturn led to a decline in electricity demand, with annual electricity consumption dipping from roughly 150 TWh in 2007 to 139 TWh in 2008. This assuaged concerns about system reliability and facilitated the closure of coal units (6 were shuttered between 2010 and 2011). By the 2011 elections, the place of coal-fired power had declined to less than 5% of total generation (as depicted in Fig. 4). In light of this much-diminished role, lingering resistance to the phase-out was largely limited to affected municipalities, fearing lost tax revenues and employment. The decision to convert the Thunder Bay and Atikokan plants to biomass helped mitigate some of these concerns (Harris et al., 2015).

3.3.1. Discursive dynamics

While the formulation of delegitimizing storylines remained largely unchanged in this phase, contextual developments

[2] While health-environment advocates largely draw on reports by the Ontario Medical Association (2000, 1998) to estimate the impacts of coal-fired generation, coal supporters appear to refer to the work of the Fraser Institute (McKitrick et al., 2005).

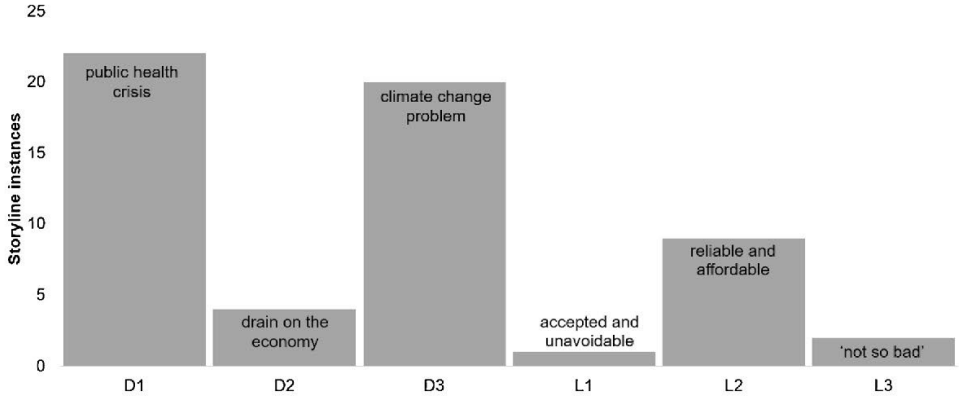


Fig. 12. Storyline instances (October 2007–October 2011).
This figure displays the results of a discursive analysis of 82 newspaper articles surrounding the coal phase-out during this period. It indicates that the storyline depicting coal-fired power as a climate change problem acquired increasing prominence at this time.

surrounding the 2008 global financial crisis and the ensuing push to develop a green economy encouraged the uptake of a storyline framing coal as a climate problem (see Figs. 12 and 13). As part of this, actors linked content-related claims about the carbon-intensity of coal to contextual factors concerning the emerging climate-economy agenda. The Ontario Clean Air Alliance, for instance, linked the elimination of coal to green economy aspirations, stating that "switching off coal for good is a great way to demonstrate that this province truly is ready for the new green global economy" (Gibbons, 2010). Similarly, the Canadian Association of Physicians for the Environment emphasized the importance of moving away from coal for ambitious climate action, asserting that it "is critical because it's the single largest greenhouse gas reduction project in North America" (Forman, 2010). To be sure, the government also increasingly tied the shutdown of coal units to its green economy agenda, suggesting that it was essential to make room for the ongoing rollout of low-carbon energy technologies (Leslie, 2009). The discursive analysis also indicates that internal tensions around the pace of the phase-out had yet to be fully resolved. Health-environment advocates attempted to leverage promising contextual developments (e.g., ambitious institutional commitments around new renewable deployment) in order to press for a more rapid

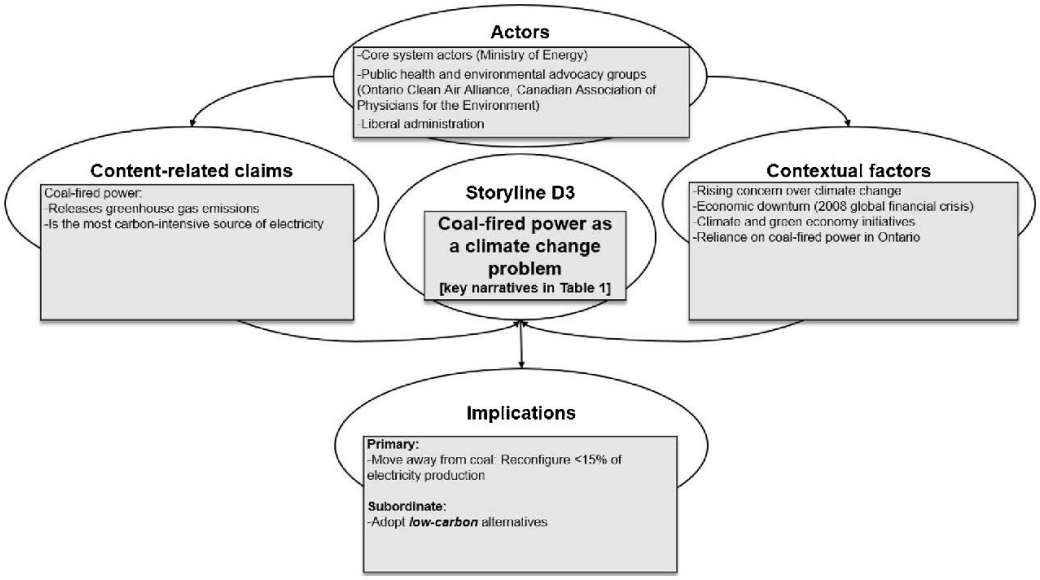


Fig. 13. Constituting components of storyline D3.
This figure shows how actors selectively wed content-related claims to context in order to craft specific narratives contributing to a storyline that frames coal-fired power as a climate change problem.

closure of coal units, proposing a 2011 target (Gibbons, 2010). Yet, the Liberal administration adhered to the 2014 deadline.

According to the discursive analysis, the number and breadth of actors engaged in legitimizing the role of coal-fired power declined markedly in this phase. What remained were a few advocacy groups, unions, and think tanks producing narratives echoing earlier debates. There are a number of possible reasons for this. First, although coal supporters would have preferred to abolish the coal phase-out altogether, it may have been considered strategic to accept the delay and withdraw until a more sympathetic political administration took power. Second, relevant actors were likely allocating their limited resources to emerging political controversies (green energy incentives, for instance). Third, some concerns had been addressed through the delay (reliability would not be sacrificed) and other compromises (converting plants to biomass). Fourth, and perhaps most importantly, the overall position of coal had declined considerably due to grid investments and unfolding developments (dampened electricity demand brought on by the economic slowdown, in particular), so the stakes were no longer as high.

3.4. October 2011–2014: coal goes out with a whimper

After the 2011 election in which the Liberals lost their majority status (due in part to other energy-related controversies), electricity demand continued to stagnate and the remaining coal-fired stations were held in reserve until they could be shut down or converted to biomass. Debates focused on more immediate political interventions in the electricity system (e.g., green energy investments and rising costs) rather than historical engagement around the coal phase-out (Rosenbloom et al., 2018). Signaling the end of the coal-fired era in the province, Nanticoke – once the largest coal plant in North America and the single most important point-source of GHG emissions in Canada (accounting for 29.3 Mt of CO2eq or 4% of Canada's total GHG emissions in 2005) – stopped burning coal in 2013 (Ontario Ministry of Energy, 2015). This was followed by the shutdown or conversion of the few remaining coal units by April 2014.

3.4.1. Discursive dynamics

The analysis suggests that discursive interactions were relatively sparse during this phase (see Fig. 14). With respect to storylines delegitimizing coal, most actors reiterated narratives from earlier periods in order to reaffirm the merits of the phase-out and celebrate its accomplishment. Environmental Defence, for instance, celebrated the climate benefits of shuttering coal units by stating that "Ontario has shown the world that bold action on climate change can be done" (Mississauga News, 2013). The Ontario Clean Air Alliance likewise submitted that moving away from coal "has led to a substantial improvement in our air quality" (Kane, 2013). Narratives legitimizing coal were limited, with only a few instances attempting to paint the move away from coal as trading off economic outcomes for environmental benefits (Adams, 2013; Vo, 2012).

4. Discussion and conclusion

This study examines framing struggles surrounding the pathway to phase-out coal in Ontario. In doing so, it generates several insights for the theory and practice of sustainability transitions. At the broadest level, it indicates that the multi-dimensional discursive approach can be usefully deployed to scrutinize the interacting political domains of sustainable energy transitions. That is, it shows promise in embracing and weaving together ideas, interests, institutions, and infrastructure. More specifically, the analysis elaborates how pathways are shaped by processes of continual negotiation among evolving considerations and priorities. Indeed, it was the dialectical interaction and layering of priorities around health-environment, climate change, as well as affordability and reliability that helped define the pathway to eliminate coal in Ontario. Framing coal in terms of these concerns modulated the envelope of possibilities considered and privileged certain courses of action. Health-environment problems, for instance, provided the

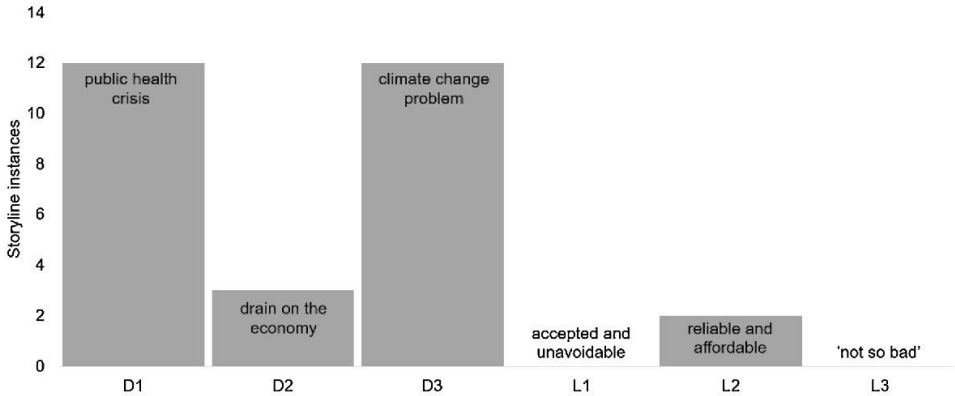


Fig. 14. Storyline instances (October 2011–April 2014).
This figure displays the results of a discursive analysis of 31 newspaper articles surrounding the coal phase-out during this period.

impetus for the phase-out as narratives linking coal to regional air quality issues catalyzed debate and imparted a sense of urgency (thousands were supposedly dying each year) that helped stimulate an accelerated response. Framing coal in relation to climate change also helped determine what might constitute an appropriate course of action. From as early as 2003, low-carbon new renewables were pursued *in addition* to cleaner burning natural gas as a replacement for coal capacity. And, even in the face of mounting resistance, decision-makers selected not to install scrubbing systems on all coal-fired units to maintain their operation. Instead, the Liberal administration opted to shutter or convert the plants to burn carbon-neutral biomass. The pace of the phase-out was also moderated by reliability and cost priorities. Yet, the move away from coal was not abandoned even when coal-fired power was no more than reserve capacity. Together, this suggests that continual negotiations among evolving considerations and problem frames helped define the pathway to phase-out coal. Perhaps most importantly however, these problem frames were not simply imposed by politically neutral and external pressures but were rather strategically leveraged by actors to shape the course of societal development.

By attending more explicitly to the implications of storylines, the analysis further elucidates how actors strategically frame issues and innovations to privilege certain institutional and infrastructural choices. Health-environment advocates, on the one hand, advanced storylines that framed coal as a serious health-environment crisis and implied a rapid phase-out. Through their discursive maneuvers, these groups persistently placed pressure on decision-makers to enact and renew commitments that would see the ramp down of coal-fired sources. This positioning was largely successful as health professionals and environmental groups were likely viewed as more credible actors than energy system operators in matters of health and environment. On the other hand, actors engaged in the operation of the electricity system, think tanks, and affected unions largely reinforced established arrangements and attempted to limit new policy commitments. They prepared storylines that married technical and economic claims to mounting reliability concerns in order to support the role of coal-fired power. This network of actors had close ties to economic interests and the operation of the electricity system, which may have bolstered their credibility on these fronts. The positioning of political parties, in contrast, was more dynamic. While there was much to gain by allying with health-environment advocates in vilifying coal, the interests of key actors in the electricity sector could not be ignored. The Conservatives (in supporting but then distancing themselves from phase-out proposals) and Liberals (in advocating a rapid phase-out but then delaying the deadline on two occasions) pivoted between these groups and their positions.

From this discussion, it may also be possible to discern more general patterns of framing struggles around sustainability transitions (see Fig. 15). These patterns reflect: (1) interactions among competing storylines; and (2) the resonance of disruptive (regime-

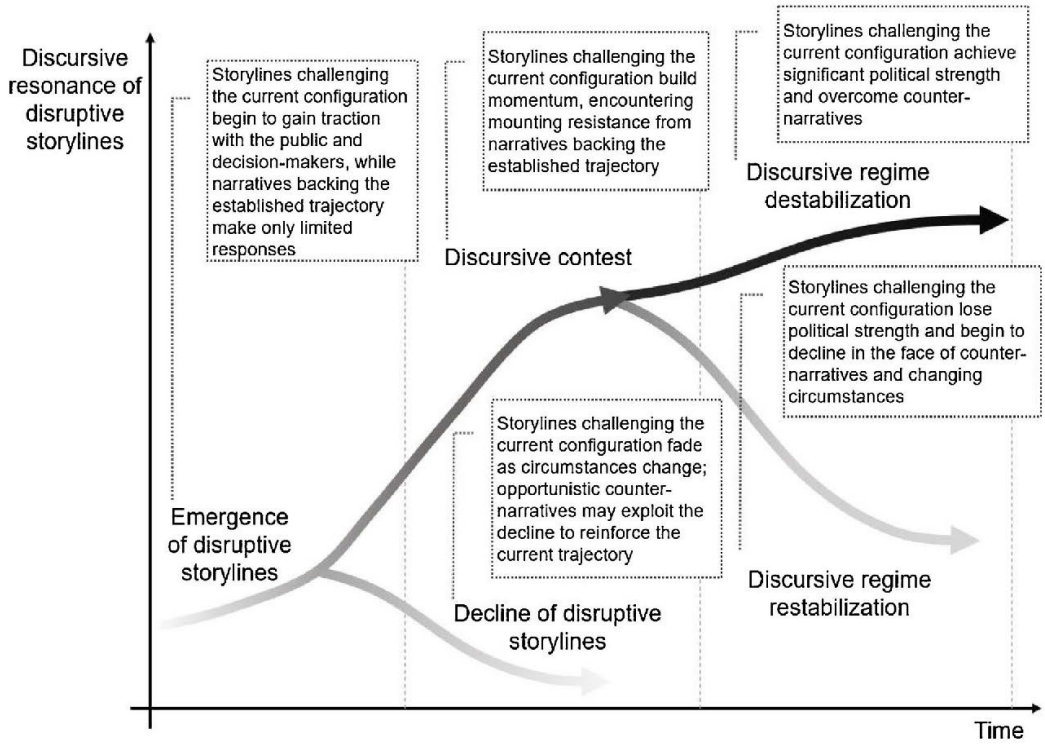


Fig. 15. Discursive patterns marking framing struggles around sustainability transitions.

challenging) storylines based on the strength and alignment of constituting components (see Section 2). While others have focused on discourses internal to the regime and what they might suggest for the stability of the socio-technical configuration (Bosman et al., 2014), here the emphasis is on outward-oriented narratives and how disruptive storylines could erode the legitimacy of the existing configuration and its trajectory (Turnheim and Geels, 2012, 2013). Five broad discursive patterns are identified: *emergence of disruptive storylines*, *decline of disruptive storylines*, *discursive contest*, *discursive regime restabilization*, and *discursive regime destabilization*. These patterns do not necessarily progress in a linear fashion but rather unfold along a variety of potential paths. For example, the emergence of disruptive storylines may be proceeded by a discursive contest and a period of discursive regime destabilization, which may then be followed by renewed contests and eventual discursive regime restabilization.

The *emergence of disruptive storylines* occurs when regime-challenging storylines begin to gain traction and only encounter limited responses. This pattern may unfold because disruptive storylines represent a minor threat and/or a concerted response would help to legitimize rival positions. In the case of the coal phase-out, this captures the period of 1998–2003 as storylines delegitimizing coal increasingly resonated within political debates in the face of only limited resistance. The *decline of disruptive storylines* takes place when regime-challenging storylines fade as the strength and alignment of their constituting components weaken. This decline may relate to changing developments (e.g., other contextual factors capture the public imagination), weakened content-related claims (e.g., claims fail to connect with evidence or experience), or a loss of credibility among key messengers (e.g., actors are implicated in a scandal). Opportunistic counter-narratives may take advantage of this decline to further undermine alternative possibilities (e.g., calling attention to unfulfilled claims about green jobs). However, disruptive storylines may re-emerge if conditions change and constituting components are updated. In contrast, a *discursive contest* may transpire if storylines challenging the system configuration gain momentum until they merit a more vigorous response. These contests may be protracted as storylines undergo several adjustments in reaction to changing circumstances and rival narratives. In the case of the coal phase-out, this reflects the period of 2003–2007 during which time regime-challenging storylines encountered mounting resistance. This discursive pattern may also mark the ongoing debate around the phase-out of internal combustion engines as some auto manufacturers have begun to advance counter-narratives about 'consumer choice' in an attempt to erode mounting support for regulatory action (Bradsher, 2017).

Two final patterns may interrupt or follow from discursive contests. *Discursive regime restabilization* may occur if disruptive storylines lose momentum in the face of intense competition from counter-narratives. During the coal phase-out, narratives that appealed to affordability and reliability had the potential to encourage discursive regime restabilization as they defended against increasingly prominent regime-challenging storylines. In an attempt to reassert core regime logics and propagate the established trajectory, counter-narratives contributed to two delays of the phase-out target. However, disruptive storylines did not lose prominence nor did a policy reversal materialize (e.g., a decision to maintain some of the coal-fired units). *Discursive regime destabilization*, in contrast, may take place if disruptive storylines sufficiently undermine counter-narratives, leading to their decline and an associated erosion of underlying regime logics. In this fashion, increasing pressures are imposed on the established trajectory until openings are created for the pursuit of alternative directions (Rosenbloom et al., 2018). In the case of the coal phase-out, this captures the period of 2007–2014 as disruptive storylines undermined and eventually routed rival storylines. This lent force to successive choices that progressively reduced the role of coal (e.g., the sequential closure of coal units) and helped veer the configuration in alternative directions.

Beyond these more theoretical contributions, findings also offer lessons for the practice of sustainability transitions. Discursive dynamics surrounding the coal phase-out point to a number of insights for actors engaged in narrative-work. First, the narratives identified in this analysis helped to *establish compelling yet simplified understandings of complex problems*. In this way, they conveyed the essential elements without delving deeply into the multiple and stubborn factors involved in air quality issues, climate change, or the operation of the electricity system. This simplification made problems seem more tractable, opening up possible responses that were perceived as having real and immediate impacts (phasing out coal would combat smog or climate change). Second, narratives focused on coal and not all sources of air and climate pollutants, *painting a single target as the villain*. In this fashion, narratives invoked longstanding symbols (heroes, villains, and victims) and suggested concrete opportunities for action, which appealed to simplified understandings. Delegitimizing storylines, for instance, implied the elimination of all coal-fired generation rather than more complex responses (carbon capture and sequestration, for instance). Third, while the results show that several considerations shaped the pathway to eliminate coal, the discursive patterns uncovered here suggest that there is potential to *provoke accelerated action by appealing to more tangible and proximate issues* (health risks and smog, in this instance). Fourth, while the stakes may be highest during the initial framing struggles, *persistent discursive work is required to update narratives and press for the achievement of outcomes over the long-term*. Narratives did not stagnate but were rather continuously updated as contextual developments unfolded and concerns evolved, linking alternately to the incidence of smog, poor nuclear performance, economic challenges, the development of a low-carbon economy, and so on. Even now, there are lingering controversies around the coal phase-out as opponents continue to question the rationale for this initiative, asserting that air quality improvements were not achieved, climate-related motivations were misplaced, and this undertaking was the root of electricity affordability troubles in the province (McKitrick and Aliakbari, 2017). This indicates that framing struggles are never fully resolved as actors continue to reinterpret and recast complex realities to promote their perceived interests.

The study also presents some important lessons for the governance of low-carbon transitions. In particular, it suggests that regulation has an important role to play in crafting effective climate change mitigation responses. While there is currently an emphasis on carbon pricing as the optimal means of promoting low-carbon transitions, it has so far been politically untenable to adopt carbon pricing regimes that are stringent enough to encourage rapid decarbonization. In light of this, the coal phase-out experience suggests that regulatory approaches may find political and environmental success where market approaches, however well-designed, encounter unforgiving political realities. Indeed, this case demonstrates that achieving ambitious GHG emission reductions can be

politically acceptable as the Ontario Liberals won four successive mandates on their record of a coal phase-out. So, although the public may not be willing to accept an explicit carbon price at the levels needed to achieve climate objectives (the shutdown of coal units would have required a carbon price of $100–130 per tonne of CO_2), regulatory action with an equivalent but implicit price might be acceptable (Jaccard, 2016). This indicates that there may be value in promoting the accelerated elimination of particularly problematic arrangements (coal-fired generation but also internal combustion engines or inefficient construction practices) through targeted regulatory measures. This experience also links to the ongoing debate concerned with accelerating the pace of sustainability transitions (Kern and Rogge, 2016; Sovacool and Geels, 2016), stressing that deliberate and rapid shifts within complex societal systems are indeed possible and may be facilitated through regulatory approaches. Similarly, this case further corroborates the importance of incorporating *regime destabilization* or *exnovation* mechanisms such as phase-outs as part of policy mixes stimulating decarbonization pathways (Kivimaa and Kern, 2016; Kungl and Geels, 2017). It is no longer sufficient to focus on support for novel technologies or the creation of an innovation ecosystem that encourages niche development. Rather, it is critical to remove institutional supports for carbon-intensive businesses practices, terminate embedded incentives for fossil fuels, and even undermine the legitimacy of unsustainable arrangements through political discourse.

Despite the promise of Ontario's coal phase-out, its achievement may have been facilitated by a unique combination of factors that could limit its replicability across jurisdictions. First, there was no coal extraction in the province, which reduced domestic employment impacts. This differs markedly from Germany, for instance, which has historically been host to a sizeable coal industry. Second, the electricity configuration in Ontario was being restructured during the adoption and early implementation of the coal phase-out, which likely limited resistance from system actors. Third, the 2008 financial crisis dampened electricity demand considerably, lessening the task of rapidly replacing electricity capacity and ensuring reliability. Fourth, a variety of other energy-related controversies (e.g., green energy subsidies and gas plant cancellations) may have diverted attention and resources away from resisting the phase-out as actors focused on what might have been perceived as more pressing issues. Yet, while contributing factors may differ across contexts, the elimination of coal-fired power in Ontario reveals how actors can strategically leverage conjunctural forces in order to exploit openings in established trajectories and accelerate low-carbon pathways.

Acknowledgements

The author gratefully acknowledges the financial support of the Social Sciences and Humanities Research Council of Canada. I would also like to thank James Meadowcroft, the participants of the 2017 Ontario Network for Sustainable Energy Policy workshop, and two anonymous reviewers for their insightful comments.

References

Adams, T., 2013. Power failure: Ontario's cost cancer started with coal. Natl. Post FP. 11.
Benford, R.D., Snow, D.A., 2000. Framing processes and social movements: an overview and assessment. Annu. Rev. Sociol. 26, 611–639. http://dx.doi.org/10.1146/annurev.soc.26.1.611.
Bosman, R., Loorbach, D., Frantzeskaki, N., Pistorius, T., 2014. Discursive regime dynamics in the Dutch energy transition. Environ. Innov. Soc. Transit. 13, 45–59. http://dx.doi.org/10.1016/j.eist.2014.07.003.
Bradsher, K., 2017. G.M. chief, in China, challenges planned bans of gasoline cars. N. Y. Times.
Cundiff, B., 2015. Ontario's Coal Phse Out: Lessons Learned from a Massive Climate Achievement. Ontario Cliean Air Alliance Research, Toronto.
Delshad, A., Raymond, L., 2013. Media framing and public attitudes toward biofuels: media framing and public attitudes toward biofuels. Rev. Policy Res. 30, 190–210. http://dx.doi.org/10.1111/ropr.12009.
Dixon-Woods, M., Agarwal, S., Jones, D., Young, B., Sutton, A., 2005. Synthesising qualitative and quantitative evidence: a review of possible methods. J. Health Serv. Res. Policy Lond. 10, 45–53.
Downs, A., 1972. Up and down with ecology: the issue-attention cycle. Public Interest 28, 37–50.
Elston, S., 2002. The issue is power and how we make it. Niagara F. Rev. B9.
Fischer, F., Forester, J. (Eds.), 1993. The Argumentative Turn in Policy Analysis and Planning. Duke University Press, Durham.
Forman, G., 2010. Hasten shutdown of coal plants. Tor. Star 20.
Fuenfschilling, L., Truffer, B., 2016. The interplay of institutions, actors and technologies in socio-technical systems — an analysis of transformations in the Australian urban water sector. Technol. Forecast. Soc. Change 103, 298–312. http://dx.doi.org/10.1016/j.techfore.2015.11.023.
Geels, F.W., Verhees, B., 2011. Cultural legitimacy and framing struggles in innovation journeys: a cultural-performative perspective and a case study of Dutch nuclear energy (1945–1986). Technol. Forecast. Soc. Change 78, 910–930. http://dx.doi.org/10.1016/j.techfore.2010.12.004.
Gibbons, J., 2000. Coal is costing us the air we breathe. Tor. Star A29.
Gibbons, J., 2004. It's time to stop giving nuclear energy special deals. The Record A11.
Gibbons, J., 2010. Greening Ontario can afford to switch off coal power now. Tor. Star 15.
Hajer, M.A., 1995. The Politics of Environmental Discourse: Ecological Modernization and the Policy Process. Clarendon Press.
Hajer, M.A., 2006. Doing discourse analysis: coalitions, practices, meaning. In: van den Brink, M., Metze, T. (Eds.), Words Matter in Policy and Planning: Discourse Theory and Method in the Social Sciences. Netherlands Geographical Studies, Utrecht Netherlands.
Harris, M., Beck, M., Gerasimchuk, I., 2015. The End of Coal: Ontario's Coal Phase-out.
Howlett, K., 2006. McGuinty admits he made bad call on coal plants. Globe Mail A.7.
Independent Electricity System Operator, 2017. Historical demand [WWW Document]. IESO. URL http://www.ieso.ca/power-data/demand-overview/historical-demand (Accessed 5 April 17).
Jaccard, M., 2016. Want an effective climate policy? Heed the evidence [WWW Document]. Policy Options. URL http://policyoptions.irpp.org/magazines/february-2016/want-an-effective-climatepolicy-heed-the-evidence/ (Accessed 28 April 17).
Jackson, D., de la Mothe, J., 2001. Nuclear regulation in transition: the atomic energy control board. In: Doern, G.B., Dorman, A., Morrison, R.W. (Eds.), Canadian Nuclear Energy Policy: Changing Ideas, Institutions, and Interests. University of Toronto Press, Scholarly Publishing Division, Toronto, pp. 96–111.
Kane, L., 2013. Whew! A breath of fresh air: atmosphere's quality in province has improved over decade, report says. Tor. Star GT. 4.
Kern, F., Rogge, K.S., 2016. The pace of governed energy transitions: agency, international dynamics and the global Paris agreement accelerating decarbonisation processes? Energy Res. Soc. Sci. 22, 13–17. http://dx.doi.org/10.1016/j.erss.2016.08.016.
Kingdon, J., 1984. Agendas, Alternatives and Public Policies. Little Brown and Company, Boston.

Kivimaa, P., Kern, F., 2016. Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. Res. Policy 45, 205–217. http://dx.doi.org/10.1016/j.respol.2015.09.008.
Kungl, G., Geels, F.W., 2017. Sequence and alignment of external pressures in industry destabilisation: understanding the downfall of incumbent utilities in the German energy transition (1998–2015). Environ. Innov. Soc. Transit. http://dx.doi.org/10.1016/j.eist.2017.05.003.
Lafleche, G., 2005. Millwrights lobbying government to keep coal-fired plant running. Standard A4.
Lee, J., Perrotta, K., 2002. Extinguish coal-fired power plants. The Record A11.
Legislative Assembly of Ontario, 2002. Select committee on alternative fuel sources. Final Report. LAO, Toronto.
Leslie, K., 2009. Four coal-fuelled power stations to be shut down in 2010. Waterloo Reg. Rec. B.8.
Lindgren, A., 2002. McGuinty promises to close coal plants: Ontario Liberals make clean energy an election platform. Ott. Citiz. A12.
Mallett, A., Jegen, M., Philion, X.D., Reiber, R., Rosenbloom, D., 2017. Smart grid framing through coverage in the Canadian media: technologies coupled with experiences. Renew. Sustain. Energy Rev. http://dx.doi.org/10.1016/j.rser.2017.06.013.
McCaffery, D., 2005. Moms get into a power struggle. Observer A1 Front.
McCarthy, S., 2007. For Liberals, a fierce election takes a lot of energy. Globe Mail Tor. Ont A. 14.
McKay, P., 1983. Electric empire: the inside story of Ontario Hydro. Between the Lines. Toronto.
McKitrick, R., Aliakbari, E., 2017. Did the Coal Phase-out Reduce Ontario Air Pollution. Fraser Institute, Vancouver.
McKitrick, R., Green, K., Schwartz, J., 2005. Pain Without Gain: Shutting down Coal-fired Power Plants Would Hurt Ontario. Fraser Institute, Vancouver.
McKitrick, R., 2017. Turns out Ontario's painful coal phase-out didn't help pollution — and Queen's Park even knew it wouldn't [WWW Document]. Financ. Post. . URL http://business.financialpost.com/fp-comment/ross-mckitrick-turns-out-ontarios-painful-coal-phase-out-didnt-help-pollution-and-queens-park-even-knew-it-wouldnt (Accessed 20 April 17).
Meadowcroft, J., 2009. What about the politics? Sustainable development, transition management, and long term energy transitions. Policy Sci. 42, 323–340. http://dx.doi.org/10.1007/s11077-009-9097-z.
Meadowcroft, J., 2011. Engaging with the politics of sustainability transitions. Environ. Innov. Soc. Transit. 1, 70–75. http://dx.doi.org/10.1016/j.eist.2011.02.003.
Ministry of the Environment and Climate Change, 2007. Go Green: Ontario's Action Plan on Climate Change. Queen's Printer for Ontario, Toronto.
Mississauga News, 2013. Enviro-champ Gore cheers ban on coal. Mississauga News 1.
Munoz, L.A.H., Huijben, J.C.C.M., Verhees, B., Verbong, G.P.J., 2014. The power of grid parity: a discursive approach. Technol. Forecast. Soc. Change 87, 179–190. http://dx.doi.org/10.1016/j.techfore.2013.12.012.
Ontario Medical Association, 1998. OMA Ground Level Ozone Position Paper. OMA, Toronto.
Ontario Medical Association, 2000. The Illness Costs of Air Pollution in Ontario: A Summary of Finding. OMA, Toronto.
Ontario Ministry of Energy, 2015. The End of Coal: An Ontario Primer on Modernizing Electricity Supply. Queen's Printer for Ontario, Toronto.
Raven, R., Kern, F., Verhees, B., Smith, A., 2016. Niche construction and empowerment through socio-political work. A meta-analysis of six low-carbon technology cases. Environ. Innov. Soc. Transit. 18, 164–180. http://dx.doi.org/10.1016/j.eist.2015.02.002.
Rein, M., Schön, D., 1993. Reframing policy discourse. In: Fischer, F., Forester, J. (Eds.), The Argumentative Turn in Policy Analysis and Planning. Duke University Press, Durham, pp. 145–166.
Roberts, J.C.D., 2017. Discursive destabilisation of socio-technical regimes: negative storylines and the discursive vulnerability of historical American railroads. Energy Res. Soc. Sci. 31, 86–99. http://dx.doi.org/10.1016/j.erss.2017.05.031.
Rosenbloom, D., Meadowcroft, J., 2014. The journey towards decarbonization: exploring socio-technical transitions in the electricity sector in the province of Ontario (1885–2013) and potential low-carbon pathways. Energy Policy 65, 670–679. http://dx.doi.org/10.1016/j.enpol.2013.09.039.
Rosenbloom, D., Berton, H., Meadowcroft, J., 2016. Framing the sun: a discursive approach to understanding multi-dimensional interactions within socio-technical transitions through the case of solar electricity in Ontario, Canada. Res. Policy 45, 1275–1290. http://dx.doi.org/10.1016/j.respol.2016.03.012.
Rosenbloom, D., Haley, B., Meadowcroft, J., 2018. Critical choices and the politics of decarbonization pathways: exploring branching points surrounding low-carbon transitions in Canadian electricity systems. Energy Res. Soc. Sci. 37, 22–36. http://dx.doi.org/10.1016/j.erss.2017.09.022.
Rosenbloom, D., 2017. Pathways: an emerging concept for the theory and governance of low-carbon transitions. Glob. Environ. Change 43, 37–50. http://dx.doi.org/10.1016/j.gloenvcha.2016.12.011.
Rowlands, I.H., 2007. The development of renewable electricity policy in the province of Ontario: the influence of ideas and timing. Rev. Policy Res. 24, 185–207.
Schmidt, V.A., 2008. Discursive institutionalism: the explanatory power of ideas and discourse. Annu. Rev. Political Sci. 11, 303–326. http://dx.doi.org/10.1146/annurev.polisci.11.060606.135342.
Shove, E., Walker, G., 2007. CAUTION! Transitions ahead: politics, practice, and sustainable transition management. Environ. Plan. A 39, 763–770. http://dx.doi.org/10.1068/a39310.
Smith, A., Stirling, A., Berkhout, F., 2005. The governance of sustainable socio-technical transitions. Res. Policy 34, 1491–1510. http://dx.doi.org/10.1016/j.respol.2005.07.005.
Smith, A., Voß, J.-P., Grin, J., 2010. Innovation studies and sustainability transitions: the allure of the multi-level perspective and its challenges. Res. Policy 39, 435–448. http://dx.doi.org/10.1016/j.respol.2010.01.023.
Smith, A., Kern, F., Raven, R., Verhees, B., 2014. Spaces for sustainable innovation: solar photovoltaic electricity in the UK. Technol. Forecast. Soc. Change 81, 115–130. http://dx.doi.org/10.1016/j.techfore.2013.02.001.
Snow, D.A., Benford, R.D., 1992. Master frames and cycles of protest. In: Morris, A.D., Mueller, C.M. (Eds.), Frontiers in Social Movement Theory. Yale University Press, New Haven, pp. 133–155.
Sovacool, B.K., Geels, F.W., 2016. Further reflections on the temporality of energy transitions: a response to critics. Energy Res. Soc. Sci. 22, 232–237. http://dx.doi.org/10.1016/j.erss.2016.08.013.
Standard, 2005. Ontario must phase out coal-fired power plants, Standard A8.
Stephenson, S., 2005. Coal phase-out called unwise: power Workers Union opposes province's plan. Observer B1 Front.
Stirling, A., 2014. Transforming power: social science and the politics of energy choices. Energy Res. Soc. Sci. 1, 83–95. http://dx.doi.org/10.1016/j.erss.2014.02.001.
Stone, D., 2001. Policy Paradox: The Art of Political Decision Making, 3rd ed. W. W Norton & Company, New York.
Swift, J., Stewart, K., 2004. Hydro: the decline and fall of Ontario's electric empire. Between the Lines. Toronto.
Teschner, N., Paavola, J., 2013. Discourses of abundance: transitions in Israel's energy regime. J. Environ. Policy Plann. 15, 447–466. http://dx.doi.org/10.1080/1523908X.2013.776954.
Toronto Star, 2005. Nuclear option dismays critics. Tor. Star.
Turnheim, B., Geels, F.W., 2012. Regime destabilisation as the flipside of energy transitions: lessons from the history of the British coal industry (1913–1997). Energy Policy 50, 35–49. http://dx.doi.org/10.1016/j.enpol.2012.04.060.
Turnheim, B., Geels, F.W., 2013. The destabilisation of existing regimes: confronting a multi-dimensional framework with a case study of the British coal industry (1913–1967). Res. Policy 42, 1749–1767. http://dx.doi.org/10.1016/j.respol.2013.04.009.
Vo, J., 2012. Haldimand county council briefs. Sachem Glanbrook Gaz. 1.
Walton-Roberts, M., Beaujot, R., Hiebert, D., McDaniel, S., Rose, D., Wright, R., 2014. Why do we still need a census? Views from the age of truthiness and the death of evidence. Can. Geogr. Géographe Can. 58, 34–47. http://dx.doi.org/10.1111/cag.12065.
Winfield, M.S., 2012. Blue-Green Province: The Environment and the Political Economy of Ontario. UBC Press, Vancouver.
Winfield, M., 2017. Environmental policy: greening the province from the dynasty to Wynne. In: Collier, C., Malloy, J. (Eds.), The Politics of Ontario. University of Toronto Press, Toronto, pp. 251–273.

Appendix 3

Paper 3: A clash of socio-technical systems: exploring actor interactions around electrification and electricity trade in unfolding low-carbon pathways for Ontario

Energy Research & Social Science 49 (2019) 219–232

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

A clash of socio-technical systems: Exploring actor interactions around electrification and electricity trade in unfolding low-carbon pathways for Ontario

Daniel Rosenbloom

School of Public Policy and Administration, Carleton University 1125 Colonel By Drive, Ottawa, K1S 5B6 ON, Canada

ARTICLE INFO

Keywords:
Socio-technical transitions
Disruption
Discourse
Energy
Low-carbon pathways
Politics

ABSTRACT

Examining interactions *within* socio-technical systems forms a staple of the literature on sustainability transitions (e.g., interactions among low-carbon challengers and carbon-intensive incumbents in the electricity system). The interactions *between* multiple socio-technical systems have, however, received more limited attention (e.g., how different systems of energy provision might come into contact as part of a low-carbon transition). In response, this study draws upon insights from transition studies and recent debates about 'disruption' to consider how different energy systems (electricity, transport, and heating) and their affiliated actors are interacting around key pillars of low-carbon pathways: expanded societal electrification and electricity trade. These dynamics are explored in the context of Ontario, Canada as this province appears to be moving along a decarbonisation pathway that is anticipated to be widely reflected across transition contexts. Steps along this pathway include the decarbonisation of the electricity system (through the procurement of low-carbon supply from domestic generators and regional interties) followed by the electrification of broader energy end-uses. Based on the analysis of actor positions surrounding climate-energy planning in Ontario, findings indicate that emerging interactions around the electrification of transport are marked by greater alignments, whereas electrification of heat and electricity trade are characterised by deeper tensions. These patterns hold implications for the acceleration of low-carbon transitions.

1. Introduction

Averting the most serious impacts of climate change will require the pursuit of low-carbon transition pathways that progressively decouple energy systems, such as transport and electricity, from greenhouse gas emissions over the coming decades [1]. It is increasingly well understood that this process of transformation will not only involve significant changes to the techno-economic make up of energy systems but will also present important consequences for the political and social arrangements that underpin modern industrial economies [2–5]. Sustainability transition studies [6] offer important insights on these processes, elucidating how energy systems might move from carbon-intensive to more sustainable arrangements over multiple decades of social and technical change.

Over the past decade, transition studies have undergone a 'political turn' to more deeply attend to the role of agency and politics in these processes of energy system change toward sustainability [7,8]. Examining the patterns of interaction among actors *within* individual socio-technical energy systems (e.g., transport) forms a staple of this body of inquiry. This work has done much to explore the many potential avenues through which emerging and incumbent actors and innovations may come into contact within low-carbon pathways in, for example, transport [9,10] and electricity [11–14] systems. This research has pointed to the varied positions and strategies that emerging networks of innovators adopt in relation to the selection environment, policy support frameworks for specific energy technologies, and alternative energy trajectories [15,16]. Transition scholars have also elaborated the considerable resistive capabilities of actors aligned with established energy systems, indicating that incumbent actors often form close alliances with decision-makers to perpetuate carbon-intensive arrangements and channel the diffusion of competing low-carbon possibilities in ways that are amenable to their interests [17–19]. In this way, incumbents may possess diverse strategies as they simultaneously sustain established business models and invest in emerging low-carbon ventures [20–22]. Yet, there can be tensions between incumbents that mirror potential cleavages within established system configurations [23] and signal processes of destabilisation [24,25]. Taken together, transition studies have shed considerable light on the complex and

E-mail address: daniel.rosenbloom@carleton.ca.

https://doi.org/10.1016/j.erss.2018.10.015
Received 7 July 2018; Received in revised form 13 October 2018; Accepted 17 October 2018

often fluid strategies adopted by actors as they vie for position in energy markets, policy debates about technology preferences, and visions for potential energy futures.

In contrast, somewhat less has been done to explicitly explore interactions *between* socio-technical systems of energy provision in the context of unfolding low-carbon pathways. Notwithstanding several important early studies which examine the interface of different energy system configurations [26–28], "[e]xisting literature on the topic often operates on the level of individual socio-technical systems" and largely misses how these systems "become connected into complexes of systems" ([29], p.1046). Indeed, prominent transition scholars have called for strands of inquiry to move beyond more singular incumbent-challenger (or niche-regime) interactions in order to engage with transition processes that cut across system boundaries [28–31]. Take, for instance, how heat and power systems or information and communication technology and transport systems may become increasingly intertwined as part of decarbonisation pathways. In light of this, there is merit in generating renewed and more sustained interest in the interactions occurring between multiple socio-technical systems within sustainability transitions.

In response, this paper seeks to further interrogate the actor interactions that take place between multiple systems of energy provision, focusing in particular on three *sites of interaction* that are bringing energy systems closer together in realising low-carbon pathways: (1) the electrification of transport, (2) the electrification of heat, and (3) electricity trade. Electrification of transport involves displacing fossil fuels within the transport system with electricity, representing a *functional site of interaction* between transport and electricity systems. Electrification of heat entails substituting carbon-intensive fuels within the heat system with electric sources, which reflects a *functional site of interaction* between heat and electricity systems. Electricity trade involves expanding the import of low-carbon electric power from neighbouring jurisdictions, signifying a *jurisdictional site of interaction* between electricity systems from different regions.

Ontario, Canada is selected as a case study to explore these three sites of interaction. This province is an appropriate case for three primary reasons. First, it appears to be following a commonly envisioned low-carbon pathway that may offer lessons for broader transition contexts. Over the past decade and a half, Ontario has moved to reduce its reliance on carbon-intensive electricity supply (e.g., the coal phase-out), expand imports of low-carbon hydroelectricity from neighboring jurisdictions, and electrify other energy end-uses. Second, Ontario has concluded one of the most extensive stakeholder consultations in its history concerning climate-energy planning as part of the 2017 Long-term Energy Plan [32]. Despite being subject to a number of important criticisms (see, for example, [33]), this consultation captures a diversity of stakeholder voices and represents the first serious attempt in this jurisdiction to simultaneously contemplate the low-carbon future of multiple energy systems as opposed to simply electric power. Lastly, while the newly elected provincial Conservative government is already beginning to dismantle the Liberal climate-energy policy legacy, it remains unclear what alternative frameworks they will introduce to address climate and environmental priorities relating to energy. In this context, the Long-term Energy Plan consultation continues to be an important source of stakeholder perspectives on alternative courses of future energy development.

In attending to the abovementioned interactions, this study deploys discursive techniques that have shown promise in uncovering the positioning of actors within transition processes [24,34–36]. In particular, this paper investigates the positions articulated by constellations of actors from multiple energy systems surrounding the three sites of interaction mentioned above. From this, the study makes three contributions to the transition literature. First, it reveals points of alignment as well as tensions that could be leveraged to accelerate the transition. Second, it distills more general patterns that may characterise energy system interactions. And third, it underscores the utility of attending to interactions between systems and the political character of these emerging connections in the context of low-carbon transitions.

The argument in this paper proceeds in the following fashion. The study begins by elaborating the analytical perspective, presenting relevant insights on system interaction and disruption. The research approach is then outlined, which draws on discursive techniques to uncover the positioning of actors. Subsequently, the argument moves to the features of the three selected energy systems: electricity, transport, and heat. The results of the analysis are then presented, followed by a discussion of the findings and concluding remarks on policy lessons and future research directions.

2. Theoretical perspective

According to transition perspectives, energy systems such as transport or electricity can be understood as co-evolving configurations of social and technical elements that together fulfill particular societal functions and support specific trajectories of societal development [37]. In this view, socio-technical systems not only consist of material elements such as infrastructures and technologies but are also made up of social components such as practices, frames of reference, markets, ownership structures, and governance mechanisms. The distinctive social and material configurations that constitute a system are also tied to constellations of actors (through ownership, operation, representation, and use) that employ various strategies to shape system development in ways that align with their perceived interests [17,38,39]. Studies adopting discursive techniques reveal how actors struggle over the framing and legitimacy of particular innovations and policy choices as they seek to (re)orient energy systems in certain directions [40–42]. Attending to *actors,* their perceived *interests,* and the way they leverage *ideas* to (re)produce particular *institutional* and *material* structures is, therefore, essential to the analysis of how energy systems may move toward sustainability [43–45].

While attracting somewhat less sustained attention in the transition literature, several useful studies offer insights on the way in which different socio-technical systems may interface with one another during this process. Early contributions have, for instance, examined the historical co-evolution of waste and electricity systems [27] along with natural gas and electricity configurations [28] in the Netherlands, detailing how symbiotic and competitive interactions helped shape the development of these systems. In their meta-analysis of transition studies, Papachristos et al. [46] similarly revealed that interactions between systems may take on a reinforcing or disruptive pattern. Still others [26] have shed light on interaction patterns among German utilities and how they might move to more sustainable arrangements through various couplings between system elements (e.g., infrastructure or supply chains). Extending this work, Sutherland et al. [47] analysed how agriculture and electricity systems interact in the context of a transition to renewable energy, highlighting how different systems may become increasingly intertwined in meeting particular societal functions. These studies not only elucidate how emerging innovations diffuse in the context of multiple socio-technical systems but also reinforce the notion that these systems may dynamically interact over time in ways that shape the course of their development. This, in turn, highlights the additional complexity and possible tensions entailed in analysing and realising transitions that involve interactions across diverse system configurations such as those that mark transformations to more sustainable arrangements. Indeed, low-carbon pathways may reconfigure the boundaries separating different systems [26].

This literature points to a number of general patterns that mark the way in which these boundaries might be reconfigured, with *competitive* and *symbiotic* forms of interaction playing particularly prominent roles. A symbiotic relationship indicates that multiple system configurations and their affiliated networks of actors may become increasingly interlinked and may even unlock mutually beneficial outcomes (e.g., increased demand for services). Under this pattern of interaction, there

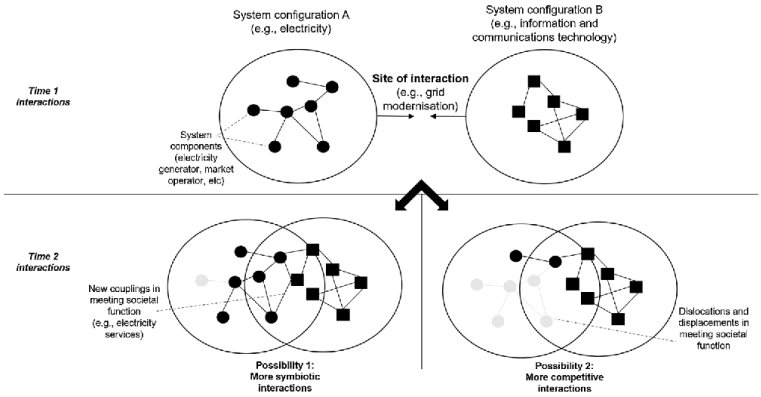


Fig. 1. Symbiotic and competitive patterns of system interaction.

may be opportunities to more closely align or even couple system components as well as the industrial and political strategies of actor constellations. A competitive relationship, in contrast, suggests that multiple systems and their affiliated actors could experience increasing frictions as gains in market share for one group of actors come at the cost of market share for another (consider, for instance, how actors in the information and communication technology configuration may disrupt traditional ways of providing electricity services). Over time, this may lead to the displacement or dislocation of certain system components (inflexible electricity generators, for example) and associated networks of actors. These patterns of interaction suggest more antagonistic actor positions (around support for grid modernisation, for instance). These patterns of interaction are summarised in Fig. 1.

Recent perspectives on 'disruption' may complement the above insights [48]. These perspectives indicate that disruption presents both pitfalls and promise for exploring sustainability transitions. While Geels [30] notes that framing transitions in terms of disruption may emphasise overly narrow firm-level processes as opposed to systems-level dynamics, others suggest that disruption 'is an important conceptual tool for analysing the ways in which socio-technical (energy) systems are changing in particular contexts' ([49], p.261). They go on to argue that disruption can apply to a series of dimensions of socio-technical systems, including actor networks, market and ownership structures, business models, regulatory frameworks, and so on. In the case of actors, disruption may imply a shift in power from incumbents to other actor groups (e.g., new entrants or actors from other socio-technical systems). This may coincide with fundamental changes to institutional and material arrangements (e.g., commitments to rollout new technologies or phase-out subsidies) that challenge the business models and assets of certain actors. Importantly, disruption in the context of large-scale energy systems may be less likely to involve the wholesale displacement of certain material or social components (in contrast to individual technological artefacts). Rather, as Winskel [50] notes, disruptive impacts in this setting may be more akin to 'creative accumulation' than 'creative destruction'. That is, the socio-technical features of energy systems (e.g., high sunk costs of large-scale capital investments and degree of regulation) may lend themselves to transition processes that reflect the layering or sedimentation of infrastructures and rules over time.

From this discussion, interactions between multiple systems and their associated actors can be thought of as occurring along a continuum, ranging from *symbiotic* to *competitive* patterns that are mediated by the degree of *disruptive potential* (see Fig. 2). In a narrow sense, disruptive potential relates to the perceptions of individual actors about the degree to which a given system interaction (e.g., the electrification of transport) could impact their business models and material holdings (i.e., whether they expect to win or lose under future system conditions). But, in a somewhat broader sense, disruptive potential also concerns the way in which wider constellations of actors perceive their general interests to align (perhaps facilitating the formation of coalitions) or come into tension under particular system interactions [51]. Examining the positioning of actors around these sites of interaction may shed light on the way in which systems are beginning to interface as low-carbon pathways unfold, pointing to potential tensions or alignments with implications for the acceleration of low-carbon transitions [8,52–54].

3. Research approach

This study deploys discursive techniques [34] to examine the way in which different energy systems and their affiliated actors are interfacing around three prominent sites of interaction: the electrification of transport, the electrification of heat, and expanded electricity trade. These sites are selected given their potential role in constituting low-carbon pathways in Ontario and other transition contexts. Energy use associated with transportation and heating together account for roughly half of Ontario's annual GHG emissions [55]. Shifting these energy end-uses to low-carbon sources of electricity is, therefore, considered to be a foundational element of decarbonisation pathways [56–58]. However, the widespread electrification of transport and heat is anticipated to

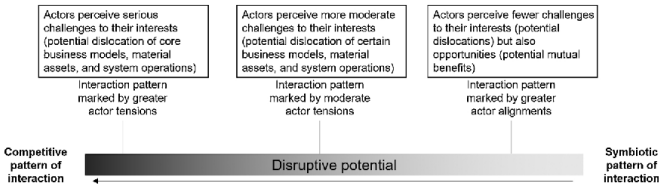


Fig. 2. Continuum of interactions.

increase demand for electricity, with some suggesting that a doubling of electricity supply is needed by 2050 in Canadian jurisdictions [56]. Leveraging Canada's unevenly distributed hydroelectric resources through enhanced interprovincial electricity trade has been pointed to as an important enabler of societal electrification and decarbonisation [56,57]. Even now, there are signs that this is beginning to take shape across Canada (consider, for instance, how British Columbia's Site C Dam and Newfoundland's Muskrat Falls are expected to displace large quantities of carbon-intensive generation in neighbouring jurisdictions). Similarly ambitious linkages between electricity systems in Ontario and Quebec (99% hydro-based) have been proposed that go beyond more limited capacity sharing agreements and bulk exports that are currently in place [38,57,59]. In this fashion, each of the above sites of interaction represent important potential steps along a pathway to decarbonisation.

Actor positions around these sites of interaction are captured from Ontario's Long-term Energy Plan (LTEP) consultation. The LTEP is a 20-year energy roadmap for Ontario developed by the Ministry of Energy through an extensive consultation and engagement process [32,60]. The plan has typically been used to inform more immediate decision-making around energy procurement and program development. Given the critical role of energy for climate change, the LTEP has also become entwined with climate policy in the province (e.g., the phase out of coal-fired power and the adoption of new renewables). Although the LTEP has historically focused on the electricity system, the most recent iteration represents the first serious attempt in this jurisdiction to integrate multiple energy systems within climate-energy planning. Drawing on background reports on the future of electricity as well as transport and heating fuels, the plan considers broad policy direction around fuel switching, the adoption of electric vehicles, conservation initiatives, renewable energy deployment, and clean electricity trade, among many other possibilities. In this way, examining stakeholder submissions and commentary around this process may reveal emerging interactions between different energy systems in the context of unfolding low-carbon pathways. And, despite being defined by both deliberate and emergent elements, energy development in Ontario over the past 15 years may mirror the initial steps of a commonly envisaged low-carbon pathway – the decarbonisation of the electricity system followed by the electrification of other energy end-uses. Thus, interactions in this jurisdiction may provide lessons for broader transition contexts.

Actor contributions surrounding the LTEP consultation were drawn from three sources. The first included formal consultation submissions from the websites of government bodies, energy firms, advocacy groups, non-governmental organisations, as well as other actors (e.g., energy consultants). These were selected using a web-based keyword search with the following parameters: 'Long-term energy plan' or 'EBR 012-8840' (the registry number of the consultation), or 'Planning Ontario's Energy Future' (the title of the primary consultation document). This yielded 51 contributions (in the form of policy reports, position papers, or formal letters) related the LTEP. Second, a further 21 publicly available reports commenting on the LTEP process were also captured by the above keyword search. Third, the above sources were supplemented by media commentary surrounding the LTEP. Media articles were selected from the Canadian Newsstream database (one of the largest news databases for Canadian media articles from a variety of regional and national outlets) using the following keywords: 'Long term energy plan' and 'Ontario'. A date range of July 2016 to September 2017 was used, which coincides with the deliberative process (the final version of the LTEP was released in October 2017). After eliminating duplicates and false positives, this search yielded 66 news articles containing statements about the LTEP.

Informed by studies drawing together discourse and transition perspectives [24,35,36,45,61], sources were analysed using a three-phase process. First, sources were reviewed to identify prominent actors surrounding the selected energy systems, which yielded over 54 policy actors. These actors were then categorised according to their affiliations with particular energy systems and their standing in these systems (Table 1). Affiliations were based on how the organisation defined itself but also its core competencies, infrastructure portfolios, and/or member representation (in the case of industry associations, for instance). Electricity producers and distributors, for instance, are affiliated with the electricity configuration as the provision of electric power is their main operational focus. Similarly, natural gas distributors are primarily affiliated with the heat system as supplying heating fuel is their core activity. Some actors have mixed affiliations as they represent voices from multiple systems (e.g., the Ontario Energy Association), hold policymaking functions that span energy systems (e.g., Ontario Ministry of Energy), or are positioned to contribute equally to the operation of more than one system (e.g., Canadian Biogas Association). Energy users and their advocates (e.g., groups representing low-income populations) also span multiple systems, but are differentiated from firms and industry associations given that they largely represent actors that do not have material holdings on the supply side. Environmental advocates, on the other hand, are separate from energy systems and for the most part critique their operation. A final group of actors are categorised under 'other'. Municipalities and their representatives are grouped here as they are significant energy users but also hold interests in multiple systems (e.g., they may own local electricity distribution companies but are also responsible for significant road infrastructure). Wind Concerns Ontario is also included here as they represent communities that oppose the deployment of wind turbines. The standing of the various actors was determined based on their market share or their societal weight in energy decision-making (particularly dominant actors are underlined in Table 1).

The second phase of the analysis involved coding actor positions with respect to electrification of transport, electrification of heat, and electricity trade. Positions were assessed at the actor level rather than at the sentence level as the goal was to determine the general orientation of each actor rather than the frequency of particular statements. This was accomplished by extracting relevant statements (ranging from a few words to several sentences in length) about the above sites of interaction and assessing whether it/they registered as supportive or negative. A supportive/negative position was coded if statements about the electrification of transport, electrification of heat, or electricity trade: were overtly favourable/unfavourable; emphasised benefits/risks; took it as given/dismissed it out of hand; or, linked its importance to other factors deemed as desirable/undesirable (e.g., support for or opposition to a specific energy source). In cases where the above did not hold or a position was not articulated, no position was recorded. Once actor positions were identified, they were mapped diagrammatically to reveal potential alignments and tensions.

A third phase drew on relevant scholarly literature (e.g., [62]), government reports (e.g. [63]), and energy data (e.g., the Independent Electricity System Operator online database) to supplement the above analysis. In light of these sources, actor positions were cross-checked and the features of the selected energy systems were fleshed out.

To be sure, this research approach is not without its limitations. As data was drawn from publicly available sources, the more covert means through which actors articulate their positions (e.g., backroom lobbying) are not reflected. Moreover, while the representation of actors was relatively broad, some voices were missing (e.g., Canadian Gas Association) or underrepresented (e.g., residential electricity and gas consumers are weakly organised in Ontario). This relates, in part, to the features of Ontario's energy systems (e.g., concentrated ownership of gas distribution) but also to the weaknesses of the LTEP consultation process itself [33] and the historical focus of this plan on electric power. A more purposive sampling method involving interviews may have helped address this issue. However, interview participation was expected to also be uneven given the politically charged nature of the electricity file in Ontario [38]. And, perhaps more importantly, statements collected after the LTEP consultation was completed would be

Table 1
Actors contributing to the LTEP and their core affiliations.

Core affiliation	Actors contributing to the LTEP process	Role
Electricity system	Association of Power Producers of Ontario	Represents independent power producers in Ontario (Bruce Power, natural gas generators, etc.)
	Bruce Power	Private nuclear power generator (~30% of electricity generation in Ontario)[a]
	Canadian Nuclear Association	Represents nuclear industry in Canada (Ontario is ~95% of the national market)[b]
	Canadian Nuclear Workers' Council	Umbrella organisation representing nuclear workers in Canada
	Canadian Solar Industries Association	Represents solar industry in Canada (Ontario is ~99% of the national market)[c]
	Canadian Wind Energy Association	Represents wind industry in Canada (Ontario is ~40% of the national market)[d]
	Electricity Distributors Association	Represents ~85% of the roughly 70 local distribution companies in Ontario[e]
	Hydro-Quebec	Vertically integrated power utility in province of Quebec (~99% hydro-based)
	Independent Electricity System Operator	Not-for-profit corporate entity responsible for power system operation and planning in Ontario
	Ontario Power Generation	Crown corporation holding nuclear, hydro, and gas assets (~50% of electricity generation in Ontario)[f]
	Ontario Sustainable Energy Association	Represents sustainable energy industry in Ontario (wind, solar, biomass, etc.)
	Ontario Waterpower Association	Represents majority of hydropower industry in Ontario (~26% of electricity generation in Ontario)[g]
	Organization of Canadian Nuclear Industries	Represents nuclear supply chain in Canada
	Power Advisory LLC	Energy consultancy
	Power Workers' Union	Represents 15,000 power workers in Ontario (~70% of unionised workforce in the electricity system)[h]
Heat system	Enbridge Gas	Owner of the two largest gas distributors in Ontario (supplying ~3.67 million customers)[i]
	Superior Propane	Largest propane distributor in Canada (commonly used in rural communities for heating)
Transport system	Canadian Vehicle Manufacturers' Association	Represents FCA Canada, Ford Motor Company of Canada, and General Motors of Canada Company (~60% of vehicles produced in Canada)[j]
Mixed affiliation	Canadian Biogas Association	Represents biogas industry in Canada
	Canadian Energy Efficiency Alliance	Think tank focused on energy efficiency solutions in Canada
	Energy Storage Canada	Represents energy storage industry in Canada
	Hydrogenics	Developer and manufacturer of hydrogen solutions headquartered in Ontario
	Ontario Energy Association	Represents interests across energy systems in Ontario (gas distributors, electricity distributors, etc.)
	Ontario Ministry of Energy	Government ministry responsible for developing energy policy in Ontario
	Ontario Petroleum Institute	Represents oil and gas industry in Ontario
	Ontario Society of Professional Engineers	Represents professional engineers in Ontario
	Plug 'N Drive	Advocates for electric vehicle adoption in Canada
Energy user advocates	Bruce Grey Poverty Task Force	Umbrella community organisation advocating for poverty reduction and elimination in Bruce Grey region
	Building Owners and Managers Association of the Greater Toronto Area	Represents commercial real estate industry in and around Toronto
	Federation of Rental-housing Providers of Ontario	Represents rental housing industry in Ontario
	Housing Services Corporation	Represents social housing industry in Ontario
	Low-income Energy Network	Advocates for access to affordable and clean energy in Ontario
	Northern Chambers of Commerce	Represents business interests in Northern Ontario
	Ontario Chamber of Commerce	Represents business interests in Ontario
	Ontario Federation of Agriculture	Represents farmers in Ontario
	Ontario Fruit and Vegetable Growers' Association	Represents fruit and vegetable farmers in Ontario
	Ontario Nonprofit Network	Represents nonprofit sector in Ontario
	United Way	Charitable organisation focused on community development and poverty reduction
	YMCA	Charitable organisation focused on community development

(*continued on next page*)

Table 1 (*continued*)

Core affiliation	Actors contributing to the LTEP process	Role
Environmental advocates	Canadian Environmental Law Association	Community legal clinic working on public health and environment in Canada
	Clean Energy Canada	Climate-energy think tank in Canada
	David Suzuki Foundation	Charitable organisation focused on the environment
	Environmental Commissioner of Ontario	Independent government watchdog on environmental policy in Ontario
	Environmental Defence	Charitable organisation focused on the environment in Canada
	Green Party of Ontario	Political party in Ontario
	Greenpeace	Environmental advocacy organisation
	Ontario Clean Air Alliance	Public health and environmental advocacy organisation in Ontario
	Ontario Rivers Alliance	Charitable fish and wildlife conservation organisation in Ontario
	Ontario Rivers Alliance	Freshwater conservation advocacy organisation in Ontario
	Pembina Institute	Climate-energy think tank in Canada
Others	Association of Municipalities Ontario	Represents the interests of 444 municipalities in Ontario[k]
	Council of the Great Lakes Region	Umbrella organisation representing regional interests around the Great Lakes
	Eastern Ontario Wardens' Caucus	Represents 13 rural municipalities in Eastern Ontario
	Wind Concerns Ontario	Anti-wind turbine advocacy organisation in Ontario

Particularly dominant actors are underlined. Data sources:
[a] Bruce Power and Independent Electricity System Operator.
[b] World Nuclear Association.
[c] IEA-PVPS national survey report for Canada.
[d] Canadian Wind Energy Association.
[e] Electricity Distributors Association.
[f] Ontario Power Generation.
[g] Ontario Waterpower Association.
[h] Power Workers' Union.
[i] Enbridge.
[j] Canadian Vehicle Manufacturers' Association.
[k] Association of Municipalities Ontario.

incommensurable with earlier commentary in light of more recent developments (e.g., the release of the final LTEP report and the election of a Conservative government in Ontario). Accounting for these challenges and trade-offs, attempts were made to triangulate actor selection and data collection by including positions articulated in formal submissions as well as commentary in reports and the media from the relevant time period.

4. Prominent features of electricity, heat, and transport systems in Ontario

Before moving to the results of the analysis, some contextualisation is necessary. Ontario is Canada's most populace province (at roughly 14 million people) and largest economy, accounting for 39% of national GDP in 2016 [64]. This jurisdiction possesses a primarily service-based economy (77.5% of GDP in 2016) but is also home to a manufacturing base (11.9% of GDP in 2016) that has gradually declined in the face of globalisation and structural adjustments. While environmental concern in the province has followed a somewhat uneven pattern since the 1970s, action on this file has steadily risen [62]. Under the former Liberal government of Ontario, the province committed to a reduction in greenhouse gas emissions of 37% below 1990 levels by 2030 and 80% below 1990 levels by 2050. A variety of climate-energy policy measures have been adopted in pursuit of these targets, including incentives for low-carbon innovations (renewables as well as electric vehicles and charging infrastructure), public transit improvements, energy retrofits, along with other actions [65]. Recent measures received funding through the proceeds of a cap-and-trade program linked to the Western Climate Initiative that came into force in January 2017 (nearly $2 billion was raised in the first year of auctions). Expanded electricity trade with neighbouring jurisdictions (e.g., Quebec) has also received attention [57].

While these developments have already begun to reshape the boundaries of the selected energy systems (electricity, heat, and transport), future climate-energy planning faces considerable uncertainty under the newly elected provincial Conservatives. The Conservatives have begun to dismantle the Liberal climate-energy policy legacy by withdrawing from the cap-and-trade program, winding down associated incentives for low-carbon innovations, and cancelling renewable energy projects that have not reached specific project milestones [66]. Despite articulating a desire to 'come down heavy' on polluters [67], agreeing to take steps to address climate change [68], and announcing a plan to allocate $425 million toward emissions-reduction initiatives [69], it remains unclear what a Conservative climate-energy framework will look like. Already, serious concerns are being raised about the emerging climate-energy policy trajectory [66,70]. And, if no credible framework is introduced, Ontario energy systems will still be subject to the federal carbon pricing backstop [71]. Thus, it is likely that electricity, heat, and transport systems will continue to be exposed to policy pressures that will bring their operations closer together.

The current *electricity system* in Ontario consists of a mix of socio-technical components that provide electricity services to users. Demand for electricity is met through nuclear (61%), hydro (24%), natural gas (9%), and new renewables (6%). This relatively low-carbon supply mix has been secured through legacy investments (e.g., in large hydroelectric dams during the first half of the twentieth century and nuclear facilities over the later half) as well as the more recent phase-out of coal-fired power (accomplished in 2014) and adoption of cleaner electricity sources [12]. Regarding governance and ownership features, electricity systems in Canada fall under provincial jurisdiction and have developed in a relatively siloed fashion (i.e., interconnections focus on the United States rather than other provinces). In contrast to American and European jurisdictions, there is a somewhat larger role for public ownership in electric power provision. However, over the past decade, Ontario has moved to encourage more private participation. Prominent actors surrounding the system include: the Ontario Ministry of Energy (which sets energy policy); the Ontario Energy Board (which regulates the system); the Independent Electricity System Operator (which operates the system); Ontario Power Generation (a crown corporation that holds the largest share of generation, much of which is nuclear); Bruce Power (a private entity that leases and operates the most sizeable nuclear facility in the province); actors representing different electricity technologies and supply options (from nuclear to solar industry associations); Hydro One (the electricity transmission and distribution service provider, which was partially privatised in 2015); local distribution companies (represented through the Electricity Distributors Association); the Power Workers' Union (which represents much of the labour force in the system and tends to be aligned with legacy assets such as nuclear power); and, energy users (who are well organised at the commercial and industrial level, but less well so at the consumer level). At present, electricity planning faces critical choices about the renewal of nuclear reactors and has been subject to controversies over affordability as electricity costs have risen by about 50% over the past decade [38]. The system is also experiencing periods of surplus baseload power, where demand is outstripped by electric power production from inflexible baseload generators such as nuclear (consider [72] for an overview).

The existing *heat system* in Ontario is constituted by social and material elements that together meet heating needs. Natural gas is the main fuel source used for space and water heating by households (at over 80% of total household energy use) and businesses (at over 90%) in the province [63]. This translates into roughly 569 Petajoules of natural gas demand for space and water heating in the commercial and residential sectors (electricity generation from natural gas, by comparison, equates to roughly one-tenth that amount). Heating equipment in the residential sector is 76% natural gas-based, with electric heat (14%), oil (5%), wood (3%), and propane (2%) accounting for the remainder [73]. While natural gas distribution networks span Ontario's major population centres, access to this energy source is less common for smaller and more remote communities. Ontario is also home to natural gas storage and trading facilities such as Dawn Hub near Sarnia. Natural gas supply is almost entirely imported from western provinces and the northeastern United States [63]. In regard to ownership and governance features, there is a significant role for private ownership in the heat system as natural gas distribution is operated according to a regulated private monopoly model. Individual heating equipment is also privately owned and widely dispersed among commercial, industrial, and residential customers. Prominent actors surrounding this system include: the Ontario Ministry of Energy (which sets energy policy); Ontario Energy Board (which regulates the system); Enbridge Gas (the largest distributor of natural gas in the province, serving 1.9 million users); Union Gas (the second largest distributor of natural gas at 1.3 million users, which was purchased by Enbridge in 2016); organisations linked to other heating sources (e.g., Superior Propane); labour representatives (though these have mixed affiliations); and, energy users. Actors affiliated with the current heat system have thus far been successful in maintaining the current trajectory, countering early suggestions that fossil fuel heating in homes built after 2030 might be phased out [74,75] and encouraging efforts to expand natural gas infrastructure [76].

The current *transport system* in Ontario consists of social and technical components that together enable the movement of people and goods (though here we are mainly concerned with personal passenger transport). The internal combustion personal automobile represents the dominant technological element of the system, numbering roughly 8 million in Ontario as of 2016 [77]. Gasoline and diesel are the main fuel sources, with electricity powering only 10,000 vehicles – 5398 battery electric and 4987 plug-in hybrids [78]. Electricity represents a more significant energy source in the mass transit space, where electric light rail and subways form the backbone of several public transit systems along with other modalities (e.g., diesel-based buses and trains). In

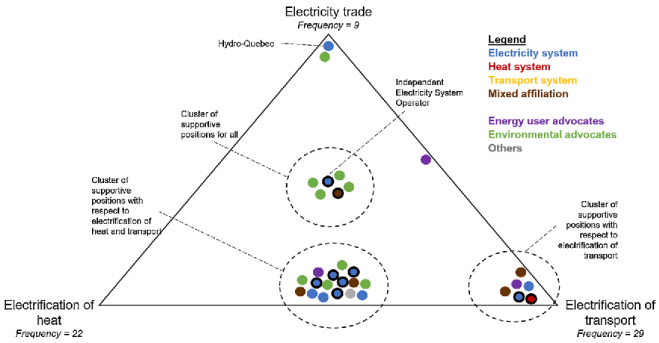


Fig. 3. Supportive actor positions surrounding electrification of transport, electrification of heat, and electricity trade in Ontario.
Each point in this diagram shows the supportive position of an actor with respect to the electrification of transport, electrification of heat, and/or electricity trade. The colour of the point reflects the affiliation of the actor. For example, a green point in the center represents an actor affiliated with environmental advocates that has adopted a supportive position with respect to electrification of transport, electrification of heat, and electricity trade. A blue point in the bottom right corner represents an actor from the electricity system that has expressed support for the electrification of transport only. A complete list of actor positions is provided in Table A1 Appendix A.

2016, Ontario motorists consumed about 15 thousand million litres of gasoline and 5 thousand million litres of diesel [79]. Nearly the entirety of crude oil products used in Ontario originate from western Canada [63]. The province, however, possesses a sizeable refining industry that meets most of domestic demand (supplemented by some gasoline imports from Quebec). Transmitting and distributing oil products involves a complex network of pipelines, refineries, tanker trucks, and service stations. Governance and ownership structures are quite mixed in this system. Personal vehicles are largely privately owned and operated, whereas mass transit systems are linked to municipally-owned transit authorities. Road networks tend to be publicly owned, though there are some privately operated toll roads. Funding for major transit projects is often shared among multiple levels of government. Prominent actors surrounding this system include: the Ontario Ministry of Transportation (which sets transport policy); Infrastructure Ontario (which oversees major infrastructure projects); transit authorities (which operate mass transit systems); vehicle manufacturers (e.g., Ford Motor Company); labor representatives (e.g., the Canadian Auto Workers); oil suppliers (e.g., service stations owned and operated by subsidiaries of international oil companies); and, energy users (though interests associated with transit and passenger vehicles are not well organised in Ontario). Vehicle manufacturing is a key industry in the province, accounting for 36.6% of annual exports [64]. As mentioned, global competitiveness challenges have placed pressure on this industry and there are internal concerns over rising electricity prices [80]. Until recently, the system also faced policy interventions related to the adoption of electric vehicles.

This discussion indicates that energy systems already share points of contact involving actors, infrastructure, and policy direction. Yet, the pursuit of low-carbon pathways is bringing these systems far closer together.

5. Results: actor positions

Analysing the actor comments from the LTEP consultation in Ontario and assessing the relationships surrounding the selected sites of interaction (*electrification of transport*, *electrification of heat*, and *electricity trade*) reveals a number of interesting patterns. According to the analysis, actor positions surrounding the *electrification of transport* are marked by more limited frictions in Ontario (see Figs. 3 and 4). Of the total actors identified, the majority (29/54) articulated supportive positions. A sizeable subset of these actors were primarily affiliated with the electricity system (11/15) and advocated altering the transport system to accommodate greater diffusion of electric vehicle modalities. Particularly dominant actors such as Bruce Power stated that 'the time is right for electric vehicles (EVs) to play a greater role in Ontario' ([81], p.19). The Power Workers' Union adopted a similar position, stating that '[s]ignificant electrification is required to meet the 2030 emission target and Ontario could realize significant economic and environmental benefits by powering made-in-Ontario zero emission EVs with the province's low-carbon hydroelectric, nuclear and biomass electricity generation' ([82], p.28). The centrality of transport electrification for a decarbonised energy future tended to be echoed by other electricity players (e.g., [83–86]). Environmental advocates (8/11) also adopted supportive positions and similarly identified climate change mitigation as a core justification (e.g., [87,88]). Moreover, several actors with mixed affiliation (5/9) supported electrification of transport. The Ontario Society of Professional Engineers [89], for instance, recommended that Ontario '[r]ealize the potential of the electric vehicle program' given that electric vehicles are now a cost-effective option. Interestingly, actors principally affiliated with the heat system also intimated support for electrification of transport. Enbridge Gas [90] assumed 'electrification in light duty' while proposing a place for

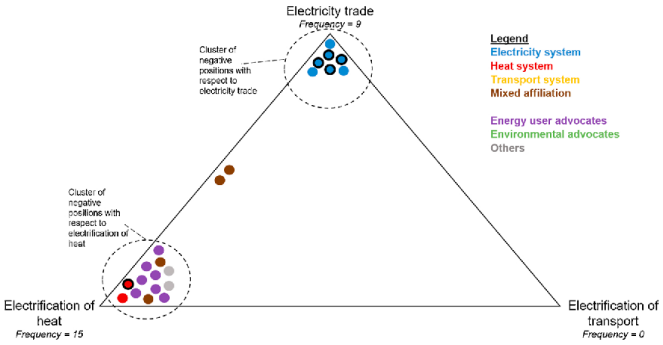


Fig. 4. Opposing actor positions surrounding electrification of transport, electrification of heat, and electricity trade in Ontario.
Each point in this diagram shows the opposing position of an actor with respect to the electrification of transport, electrification of heat, and/or electricity trade. The colour of the point reflects the affiliation of the actor. For example, a blue point at the top represents an actor affiliated with the electricity system that has signalled a negative position with respect to electricity trade. A brown point left of center represents an actor with mixed affiliation that has articulated opposition to the electrification of heat and electricity trade.

natural gas in the heavy duty transport space. Importantly, no opposing positions with respect to electrification of transport were recorded.

In contrast, results indicate that actor positions surrounding the *electrification of heat* are marked by greater tensions. Of the total actors captured, a somewhat more limited group (22/54) advanced support for the electrification of heat. Just less than half of these actors were affiliated with the electricity system (9/15) and five hold particularly dominant roles in the system. Climate change mitigation was again invoked as part of these positions. The Association of Power Producers of Ontario ([83], p.9), for instance, suggested that '[o]ne of the most promising strategies for simultaneously prompting new investment, encouraging innovation and reducing carbon emissions is to provide for increasing levels of electrification, particularly in buildings'. They went on to state that 'there may be cost challenges to overcome in some types of electrification' (undoubtedly in reference to competition with natural gas heating), but claimed that 'electrified services are likely to be much more precisely controllable, thereby attracting retail consumer interest, while simultaneously helping the Ontario grid to mitigate the challenge of Surplus Baseload Generation and enabling the most comprehensive options for decarbonisation of the economy as a whole'. Similarly, the Ontario Power Generation indicated that '[s]ince Ontario's electricity system has already been largely decarbonised through the phase-out of coal, greater electrification of the transportation and buildings sector will be required' ([91], p.3). The Canadian Solar Industries Association ([85], p.9) echoed these points, asserting that '[e]lectrification of transportation, industrial processes, and *heating in buildings* is widely viewed as essential to meeting GHG emission reduction targets' (emphasis added). Several environmental advocates (8/11) also noted the benefits of electrifying heat for climate objectives. The David Suzuki Foundation ([88], p.2), for instance, recommended the 'full phase-out of natural gas as a heating source' while supporting a 'major expansion of geothermal and electric heating systems'.

A number of actors (15/54) articulated opposing positions regarding the electrification of heat, focusing primarily on the cost of shifting to electric heat sources. Resistance was mounted by actors who hold an interest in the heat system. Enbridge Gas [90], as the dominant player, advanced that it would be far more costly to heat homes with electricity than with natural gas, recommending support for emerging 'renewable natural gas' possibilities such as injecting biomethane (upgraded biogas) into the natural gas network (see [92] for an overview of this process). They also argued that emerging low-carbon electricity sources such as solar and wind have intermittency challenges, whereas renewable natural gas would benefit from existing natural gas infrastructure to deliver a reliable supply. The Ontario Energy Association ([93], p.V), which represents natural gas suppliers among other energy firms, expressed serious reservations about electrification of heat and suggested that 'any consideration of an option to switch the heat source of existing buildings from natural gas to electricity should be costed, as this option may involve significant infrastructure investment requirements and have significant impacts on annual energy affordability for consumers and on Ontario's economy'. Similarly, the Ontario Society of Professional Engineers ([89], p.7) held that the 'large-scale electrification of homes, businesses, and industry would have significant negative impacts for economic and affordability considerations'. Energy user advocates (7/12) tended to implicitly dismiss the electrification of heat by recommending the expansion of natural gas networks, highlighting the importance of expanding access to affordable energy options in rural and more remote communities. The Ontario Federation of Agriculture ([94], p.1), for instance, stated that 'natural gas is a strategic competitive necessity for the economic development of rural Ontario'. They pointed to opportunities for natural gas heating and the use of agricultural byproducts as a feedstock for biomethane injected into the natural gas distribution system. Northern business leaders similarly recommended that the government '[e]xpand access to natural gas pipelines' and '[t]reat the expansion… as a public good' ([95], p.2).

The analysis also revealed tensions surrounding *electricity trade*. Of the total actors captured (54), only nine articulated supportive positions with respect to electricity trade. Of these, only one (of 15) had ties to the domestic electricity system. Given its more neutral role in coordinating the electricity market, the Independent Electricity System Operator ([96], p.15) was receptive to imports as a potential replacement for existing domestic generators as contracts expire, stating that 'opportunities also exist for greater electricity trade between Ontario and its neighbours'. Unsurprisingly, Hydro-Quebec [97] (the vertically-integrated public utility in Quebec) argued that expanded electricity trade would be to the advantage of Ontario through reduced electricity costs and clean power supply. Highlighting affordability and sustainability issues, a number of environmental proponents (5/11) advanced supportive positions with respect to electricity trade (e.g., [87,98]). Some viewed this as not only a way to secure low-carbon energy supply from Quebec but also as a means to accelerate the retirement of nuclear reactors in Ontario [88].

A range of actors (9/54) raised concerns about electricity trade as part of their positions. The majority of these actors (7/15) were affiliated with the domestic electricity system. The Association of Power Producers of Ontario, for instance, stated that increased electricity imports from Quebec would 'threaten to undercut a competitive marketplace and long-term planning' and that 'Ontario already has a surplus of energy, so it's very difficult to see how this deal or any other sole-source deal with Quebec could benefit the province and its ratepayers' [99]. The Power Workers' Union advanced somewhat similar arguments, asserting that '[p]ursuing firm imports from Quebec to displace low-carbon nuclear or to supplement our province's variable, expensive wind energy doesn't make environmental or economic sense' [100]. The Ontario Society of Professional Engineers argued that they 'see Quebec's interests reflected' but 'all of the costs and risks seem to fall on Ontario', noting that increased electricity trade 'will increase costs to the ratepayer and hurt Ontario's economy' [101]. Even some proponents of emerging low-carbon innovations viewed trade negatively, highlighting its risks and indicating that it would 'necessitate major transmission expansions' ([86], p.15).

6. Discussion and conclusion

From this analysis, it is possible to discern the emerging character of interactions between energy systems in Ontario within unfolding low-carbon pathways (see Fig. 5). Actor positions surrounding the LTEP consultation indicate more symbiotic patterns of system interaction around the *electrification of transport*, with statements tending to highlight the economic, technical, and environmental promise of this interaction. As previously discussed (see Section 2), this pattern may relate to actor perceptions about potential disruptions. While the electrification of transport implies progressively displacing conventional carbon-intensive fuels, actors did not deeply engage with the potential disruptions this could suggest for their business models or the operation of the systems involved (note that Ontario is not home to an

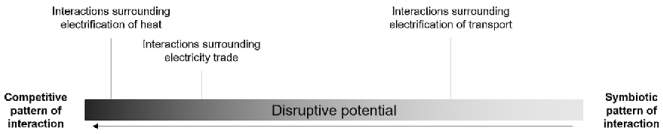


Fig. 5. Summary of emerging patterns of system interactions in Ontario.

oil extraction industry). Instead, many focused on mutual benefits for actors affiliated with the electricity and transport systems (e.g., growing sales of electric vehicles, increasing electric vehicle manufacturing in Ontario, and expanding the market for electricity). Particularly dominant actors in the electricity system (e.g., Ontario Power Generation and Power Workers' Union) articulated support for the electrification of transport given its potential role in easing oversupply issues, growing the market for electricity, and addressing climate commitments. Emerging electricity players (e.g., proponents of new renewables), environmental advocates (e.g., Ontario Clean Air Alliance), and actors with mixed affiliations (e.g., Plug 'N Drive) also expressed support in light of potential market opportunities and climate considerations. Importantly, no opposition was recorded. Given this, there may be room to further explore potential alignments among actor constellations and to leverage these emerging connections to accelerate the electrification of transport in Ontario. As the provincial Conservative government has rejected carbon pricing, policy responses might focus on promoting additional electric vehicle manufacturing capacity in Ontario, establishing an electric vehicle sales standard [102], or even announcing the long-term phase-out of fossil fuel vehicles [103] (as is the case in Britain and France, for example).

There is, however, also room for caution in identifying and leveraging potential alignments around the electrification of transport. Despite sharing interests in this form of electrification, environmental advocates and dominant electricity players hold conflicting views on the role of nuclear power in Ontario's energy future. This point of contention could militate against more lasting alignments. Perhaps most importantly, however, the transition to electric transport remains in its infancy and tensions may only begin to emerge as the threat becomes more concrete and immediate. Indeed, actor positions articulated as part of the LTEP process have yet to seriously contemplate potential disruptions to: (1) the current dealership model, if Tesla, with its direct-to-customer sales model, gains market share; (2) the vehicle service market, given the decreased maintenance required for electric vehicles; (3) to vehicle ownership practices, if electric transport solutions enable autonomous or collective transportation modalities (consider, for example, [104]); and, (4) government revenues, as gas taxes dwindle in the face of widespread electric vehicle adoption. Dominant actors in the transport system (i.e., vehicle manufacturers), for instance, focused on near-term concerns about rising electricity prices rather than the long-term challenges presented by the electrification of transport. This silence may not only concern the distant nature of the threat but could also relate to the venue in which statements were uttered (the LTEP has historically been an electricity planning process), a recognition that the future of the fossil fuel-based automobile will be decided elsewhere (Ontario accounts for about 2% of global vehicle production [105]), and a decision not to explicitly confront and therefore validate rival positions [36,106].

In contrast, actor positions around the *electrification of heat* in Ontario point to a more competitive pattern of system interaction. Actor positions are marked by greater tensions, framing the electrification of heat as either a central element of climate action or as an obstacle to affordability and competitiveness. According to the positions articulated in the LTEP consultation, actors have tended to view electric heat as a (low-carbon) substitute for natural gas-based heat. In this way, actors appear to recognise the serious disruptive potential embodied by the electrification of heat (it represents a zero-sum game). As with the electrification of transport, particularly dominant electricity players have advocated the adoption of electric heat solutions given the opportunity to expand the electricity market, address issues with surplus baseload generation, and meet climate commitments. Environmental groups have found some common ground here given the potential to erode the dominant place of carbon-intensive heating in Ontario. In contrast, Enbridge Gas and an array of actors concerned with energy affordability (farmers, business interests, rural municipalities, and others) have signaled their opposition to the electrification of heat given the cost differentials between electric and natural gas-based heating. Many have also argued for expanded access to natural gas, which could lock-in this fuel as the default heating source for decades to come. If the deep tensions around this site of interaction are not relaxed, there may only be limited opportunity to accelerate the electrification of heat without considerable political costs. And, at present, decision-makers appear to have little appetite for this type of change given the Conservative government's preoccupation with energy affordability.

Actor positions surrounding *electricity trade* in Ontario also suggest a more competitive pattern of interaction. Actors have staked out contending positions, framing electricity trade as an opportunity to simultaneously advance climate and energy affordability priorities or a challenge to energy sovereignty and regional economic development. These patterns may relate to actor perceptions about potential disruptions. Opposing voices are concentrated around Ontario's electricity system as expanded electricity trade could expose the system to long-term competitive pressures from relatively low-cost hydroelectric imports, displacing power from costly domestic generators (natural gas peaking plants), undermining the rationale for nuclear reactor refurbishments [38,57], and weakening the place of power workers. It was also suggested that relying on out-of-province electricity sources could break the longstanding ties between the electricity system and domestic economic development. In contrast, Hydro-Quebec, the Ministry of Energy, the Independent Electricity System Operator, and a number of environmental advocates (e.g., Clean Energy Canada) advanced favourable statements regarding electricity trade as it could increase efficiencies and help drive decarbonisation in the electricity system. Energy users tended to be silent on the subject despite the fact that relatively low-cost hydroelectricity from Quebec could help address affordability concerns [107]. These tensions point to more limited opportunities to accelerate expanded electricity trade unless dominant electricity players are weakened (by cost-reduction measures or pressure from emerging innovations, for example) or broader societal interests (around energy affordability and climate) are more effectively mobilised.

Beyond this, the analysis offers broader lessons for the theory and practice of low-carbon transitions. In particular, it contributes to and aims to reinvigorate the strand of research focusing on interactions between socio-technical systems [26–28]. This paper adapts these perspectives and draws on more recent debates about disruption to investigate functional and jurisdictional interactions among energy systems in the context of unfolding low-carbon pathways. In doing so, the study demonstrates that scrutinising these patterns of interaction is not only valuable for elucidating historical processes of change but may also prove useful in understanding emerging political dynamics with implications for the pace of low-carbon transitions. On the one hand, more symbiotic patterns of interaction reflect less intense sites of contestation between system configurations and point to actor alignments that might be leveraged to accelerate low-carbon transitions (by, for example, building broader constituencies around particular climate policies) – though there is potential for frictions to intensify over time as more radical innovation trajectories open. More competitive patterns, on the other hand, are marked by greater tensions that may act as impediments to decarbonisation efforts – though there is a spectrum of disruptive potentials that may mediate the strength of opposition.

Findings also suggest that low-carbon pathways will not only be defined by interactions isolated to single socio-technical systems (niche-regime or incumbent-challenger dynamics) but will relate to the interface of multiple system configurations. Analysts and policymakers would, therefore, do well to more deeply consider how emerging sites of interaction might open and accelerate transition pathways toward decarbonisation. Take, for example, how efforts to simultaneously support low-carbon niches (e.g., investing in the deployment of wind and solar electricity technologies) and destabilise carbon-intensive regimes (e.g., through the removal of subsidies for fossil fuels) might be

complemented by measures that begin to reshape the boundaries between different systems (e.g., by facilitating electrification), deepening challenges for carbon-intensive configurations and creating new opportunities for low-carbon possibilities.

However, caution is merited. Attending to the patterns of interaction between energy systems highlights the complexity of governing sustainability transitions. As Raven [27] reminds us, policies that target one system may directly or indirectly impact upon one or more other systems, modulating the course of societal development in unforeseen ways. This study corroborates this observation and underscores the importance of considering the multiple system interactions that could be shaped by and help define transition pathways.

While this study has examined interactions around three oft-cited components of decarbonisation pathways, there are numerous others that will have implications for the pace and character of low-carbon transitions. Consider, for instance, sites of interaction surrounding: stringent clean fuel standards (for transport and agriculture systems); net-zero energy codes for buildings (for building, information, and electricity systems); grid modernisation efforts (for information and communication technology and electricity systems); or even, frameworks to promote carbon dioxide removal (for agriculture and electricity systems). These sites of interaction will reshape the boundaries of the systems involved and the conditions under which constellations of actors seek to advance their perceived interests. Together, they represent fruitful terrain for future transition studies seeking to understand how socio-technical systems and associated actor networks may interface as low-carbon pathways unfold. But perhaps most importantly, this analysis suggests that the interactions taking place *between* socio-technical systems (as opposed to those occurring *within* individual systems) merit further attention in sustainability transitions research.

Declaration of interest

None.

Acknowledgements

The author gratefully acknowledges the financial support of the Social Sciences and Humanities Research Council of Canada. I would also like to thank James Meadowcroft, Alexandra Mallett, Glen Toner, and three anonymous reviewers for their very helpful comments.

Appendix A

Table A1
Articulated actor positions.

	Supportive positions			Opposing positions		
	Electrification of heat	*Electrification of transport*	*Electricity trade*	*Electrification of heat*	*Electrification of transport*	*Electricity trade*
Electricity system						
Association of Power Producers of Ontario	x	x				x
Bruce Power		x				x
Canadian Nuclear Association	x	x				x
Canadian Nuclear Workers' Council		x				x
Canadian Solar Industries Association	x	x				
Canadian Wind Energy Association	x	x				
Electricity Distributors Association	x	x				
Hydro Quebec			x			
Independent Electricity System Operator	x	x	x			
Ontario Power Generation	x	x				
Ontario Sustainable Energy Association						x
Ontario Waterpower Association						x
Organization of Canadian Nuclear Industries	x	x				
Power Advisory LLC						
Power Workers' Union	x	x				x
Transport system						
Canadian Vehicle Manufacturers' Association						
Heating system						
Enbridge		x		x		
Superior Propane				x		
Mixed affiliation						
Canadian Biogas Association				x		
Canadian Energy Efficiency Alliance						
Energy Storage Canada						
Hydrogenics	x	x				
Ontario Energy Association				x		x
Ontario Ministry of Energy	x	x	x			
Ontario Petroleum Institute		x		x		
Ontario Society of Professional Engineers		x		x		x
Plug 'N Drive	x	x				
Energy user advocates						
Bruce Grey Poverty Task Force				x		
Building Owners and Managers Association of the Greater Toronto Area		x		x		
Federation of Rental-housing Providers of Ontario						
Housing Services Corporation						
Low-income Energy Network	x	x				
Northern Chambers of Commerce				x		
Ontario Chamber of Commerce				x		

(*continued on next page*)

Table A1 (*continued*)

	Supportive positions			Opposing positions		
	Electrification of heat	*Electrification of transport*	*Electricity trade*	*Electrification of heat*	*Electrification of transport*	*Electricity trade*
Ontario Federation of Agriculture		x	x	x		
Ontario Fruit and Vegetable Growers' Association				x		
Ontario Nonprofit Network						
United Way				x		
YMCA						
Environmental advocates						
Canadian Environmental Law Association	x	x				
Clean Energy Canada	x	x	x			
David Suzuki Foundation	x	x	x			
Environmental Commissioner of Ontario	x	x	x			
Environmental Defence	x	x				
Green Party of Ontario			x			
Greenpeace	x	x				
Ontario Clean Air Alliance	x	x	x			
Ontario Federation of Anglers and Hunters						
Ontario Rivers Alliance						
Pembina Institute	x	x				
Others						
Association of Municipalities Ontario				x		
Council of the Great Lakes Region	x	x				
Eastern Ontario Wardens' Caucus				x		
Wind concerns Ontario						

References

[1] IPCC, Climate Change 2014: Mitigation of Climate Change: Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014.

[2] A. Cherp, V. Vinichenko, J. Jewell, E. Brutschin, B.K. Sovacool, Integrating techno-economic, socio-technical and political perspectives on national energy transitions: a meta-theoretical framework, Energy Res. Soc. Sci. 37 (2018) 175–190, https://doi.org/10.1016/j.erss.2017.09.015.

[3] D. Rosenbloom, Pathways: an emerging concept for the theory and governance of low-carbon transitions, Glob. Environ. Change 43 (2017) 37–50, https://doi.org/10.1016/j.gloenvcha.2016.12.011.

[4] B. Turnheim, F. Berkhout, F.W. Geels, A. Hof, A. McMeekin, B. Nykvist, D.P. van Vuuren, Evaluating sustainability transitions pathways: bridging analytical approaches to address governance challenges, Glob. Environ. Change 35 (2015) 239–253, https://doi.org/10.1016/j.gloenvcha.2015.08.010.

[5] M.A.E. van Sluisveld, A.F. Hof, S. Carrara, F.W. Geels, M. Nilsson, K. Rogge, B. Turnheim, D.P. van Vuuren, Aligning integrated assessment modelling with socio-technical transition insights: an application to low-carbon energy scenario analysis in Europe, Technol. Forecast. Soc. Change (2018), https://doi.org/10.1016/j.techfore.2017.10.024.

[6] J. Markard, R. Raven, B. Truffer, Sustainability transitions: an emerging field of research and its prospects, Res. Policy 41 (2012) 955–967, https://doi.org/10.1016/j.respol.2012.02.013.

[7] J. Köhler, F.W. Geels, F. Kern, E. Onsongo, A. Wieczorek, A Research Agenda for the Sustainability Transitions Research Network, Sustainability Transitions Research Network, (2017).

[8] C. Roberts, F.W. Geels, M. Lockwood, P. Newell, H. Schmitz, B. Turnheim, A. Jordan, The politics of accelerating low-carbon transitions: towards a new research agenda, Energy Res. Soc. Sci. 44 (2018) 304–311, https://doi.org/10.1016/j.erss.2018.06.001.

[9] M. Dijk, A socio-technical perspective on the electrification of the automobile: niche and regime interaction, Int. J. Automot. Technol. Manage. 14 (2014) 158, https://doi.org/10.1504/IJATM.2014.060749.

[10] B. Elzen, F.W. Geels, P.S. Hofman, K. Green, Socio-technical scenarios as a tool for transition policy: an example from the traffic and transport domain, in: B. Elzen, F.W. Geels, K. Green (Eds.), Syst. Innov. Transit. Sustain.—Theory Evid. Policy, Edward Elgar Publishing, Cheltenham, UK / Northampton, MA, USA, 2004, pp. 251–281 (Accessed May 11, 2016), http://doc.utwente.nl/48467/.

[11] T.J. Foxon, Transition pathways for a UK low carbon electricity future, Energy Policy 52 (2013) 10–24, https://doi.org/10.1016/j.enpol.2012.04.001.

[12] D. Rosenbloom, J. Meadowcroft, The journey towards decarbonization: exploring socio-technical transitions in the electricity sector in the province of Ontario (1885–2013) and potential low-carbon pathways, Energy Policy 65 (2014) 670–679, https://doi.org/10.1016/j.enpol.2013.09.039.

[13] A. Smith, F. Kern, R. Raven, B. Verhees, Spaces for sustainable innovation: solar photovoltaic electricity in the UK, Technol. Forecast. Soc. Change 81 (2014) 115–130, https://doi.org/10.1016/j.techfore.2013.02.001.

[14] G. Verbong, F.W. Geels, The ongoing energy transition: lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960–2004), Energy Policy 35 (2007) 1025–1037, https://doi.org/10.1016/j.enpol.2006.02.010.

[15] R. Raven, F. Kern, A. Smith, S. Jacobsson, B. Verhees, The politics of innovation spaces for low-carbon energy: introduction to the special issue, Environ. Innov. Soc. Transit. 18 (2016) 101–110, https://doi.org/10.1016/j.eist.2015.06.008.

[16] R. Raven, F. Kern, B. Verhees, A. Smith, Niche construction and empowerment through socio-political work. A meta-analysis of six low-carbon technology cases, Environ. Innov. Soc. Transit. 18 (2016) 164–180, https://doi.org/10.1016/j.eist.2015.02.002.

[17] F.W. Geels, Regime resistance against low-carbon transitions: introducing politics and power into the multi-level perspective, Theory Cult. Soc. 31 (2014) 21–40, https://doi.org/10.1177/0263276414531627.

[18] D.J. Hess, Sustainability transitions: a political coalition perspective, Res. Policy 43 (2014) 278–283, https://doi.org/10.1016/j.respol.2013.10.008.

[19] M.M. Smink, M.P. Hekkert, S.O. Negro, Keeping sustainable innovation on a leash? Exploring incumbents' institutional strategies, Bus. Strategy Environ. 24 (2015) 86–101, https://doi.org/10.1002/bse.1808.

[20] A. Bergek, C. Berggren, T. Magnusson, M. Hobday, Technological discontinuities and the challenge for incumbent firms: destruction, disruption or creative accumulation? Res. Policy 42 (2013) 1210–1224, https://doi.org/10.1016/j.respol.2013.02.009.

[21] C. Berggren, T. Magnusson, D. Sushandoyo, Transition pathways revisited: established firms as multi-level actors in the heavy vehicle industry, Res. Policy 44 (2015) 1017–1028, https://doi.org/10.1016/j.respol.2014.11.009.

[22] J. Ingram, D. Maye, J. Kirwan, N. Curry, K. Kubinakova, Interactions between niche and regime: an analysis of learning and innovation networks for sustainable agriculture across Europe, J. Agric. Educ. Ext. 21 (2015) 55–71, https://doi.org/10.1080/1389224X.2014.991114.

[23] L. Fuenfschilling, B. Truffer, The structuration of socio-technical regimes—conceptual foundations from institutional theory, Res. Policy 43 (2014) 772–791, https://doi.org/10.1016/j.respol.2013.10.010.

[24] R. Bosman, D. Loorbach, N. Frantzeskaki, T. Pistorius, Discursive regime dynamics in the Dutch energy transition, Environ. Innov. Soc. Transit. 13 (2014) 45–59, https://doi.org/10.1016/j.eist.2014.07.003.

[25] B. Turnheim, F.W. Geels, Regime destabilisation as the flipside of energy transitions: Lessons from the history of the British coal industry (1913–1997), Energy Policy 50 (2012) 35–49, https://doi.org/10.1016/j.enpol.2012.04.060.

[26] K. Konrad, B. Truffer, J.-P. Voß, Multi-regime dynamics in the analysis of sectoral transformation potentials: evidence from German utility sectors, J. Clean. Prod. 16 (2008) 1190–1202, https://doi.org/10.1016/j.jclepro.2007.08.014.

[27] R. Raven, Co-evolution of waste and electricity regimes: multi-regime dynamics in the Netherlands (1969–2003), Energy Policy 35 (2007) 2197–2208, https://doi.org/10.1016/j.enpol.2006.07.005.

[28] R. Raven, G. Verbong, Multi-regime interactions in the Dutch energy sector: the case of combined heat and power technologies in the Netherlands 1970–2000,

Technol. Anal. Strateg. Manage. 19 (2007) 491–507, https://doi.org/10.1080/09537320701403441.
[29] J. Schot, L. Kanger, Deep transitions: emergence, acceleration, stabilization and directionality, Res. Policy 47 (2018) 1045–1059, https://doi.org/10.1016/j.respol.2018.03.009.
[30] F.W. Geels, Disruption and low-carbon system transformation: progress and new challenges in socio-technical transitions research and the multi-level perspective, Energy Res. Soc. Sci. 37 (2018) 224–231, https://doi.org/10.1016/j.erss.2017.10.010.
[31] F.W. Geels, The multi-level perspective on sustainability transitions: responses to seven criticisms, Environ. Innov. Soc. Transit. 1 (2011) 24–40, https://doi.org/10.1016/j.eist.2011.02.002.
[32] Ontario Ministry of Energy, Planning Ontario's Energy Future: A Discussion Guide to Start the Conversation, Queen's Printer for Ontario, Toronto, 2016.
[33] M. Winfield, Electricity system planning and sustainability assessment in Ontario, Canada, in: R. Gibson (Ed.), Sustain. Assess. Appl. Oppor, Routledge, London, 2016, pp. 146–168.
[34] F. Kern, K.S. Rogge, Harnessing theories of the policy process for analysing the politics of sustainability transitions: a critical survey, Environ. Innov. Soc. Transit. 27 (2018) 102–117, https://doi.org/10.1016/j.eist.2017.11.001.
[35] A. Leipprand, C. Flachsland, Regime destabilization in energy transitions: the German debate on the future of coal, Energy Res. Soc. Sci. 40 (2018) 190–204, https://doi.org/10.1016/j.erss.2018.02.004.
[36] D. Rosenbloom, H. Berton, J. Meadowcroft, Framing the sun: a discursive approach to understanding multi-dimensional interactions within socio-technical transitions through the case of solar electricity in Ontario, Canada, Res. Policy 45 (2016) 1275–1290, https://doi.org/10.1016/j.respol.2016.03.012.
[37] F.W. Geels, B.K. Sovacool, T. Schwanen, S. Sorrell, Sociotechnical transitions for deep decarbonization, Science 357 (2017) 1242–1244, https://doi.org/10.1126/science.aao3760.
[38] D. Rosenbloom, B. Haley, J. Meadowcroft, Critical choices and the politics of decarbonization pathways: exploring branching points surrounding low-carbon transitions in Canadian electricity systems, Energy Res. Soc. Sci. 37 (2018) 22–36, https://doi.org/10.1016/j.erss.2017.09.022.
[39] A. Stirling, Transforming power: social science and the politics of energy choices, Energy Res. Soc. Sci. 1 (2014) 83–95, https://doi.org/10.1016/j.erss.2014.02.001.
[40] F.W. Geels, B. Verhees, Cultural legitimacy and framing struggles in innovation journeys: A cultural-performative perspective and a case study of Dutch nuclear energy (1945–1986), Technol. Forecast. Soc. Change 78 (2011) 910–930, https://doi.org/10.1016/j.techfore.2010.12.004.
[41] J. Lilliestam, S. Hanger, Shades of green: centralisation, decentralisation and controversy among European renewable electricity visions, Energy Res. Soc. Sci. 17 (2016) 20–29, https://doi.org/10.1016/j.erss.2016.03.011.
[42] N. Teschner, J. Paavola, Discourses of abundance: transitions in Israel's energy regime, J. Environ. Policy Plan. 15 (2013) 447–466, https://doi.org/10.1080/1523908X.2013.776954.
[43] T.J. Foxon, P.J.G. Pearson, S. Arapostathis, A. Carlsson-Hyslop, J. Thornton, Branching points for transition pathways: assessing responses of actors to challenges on pathways to a low carbon future, Energy Policy 52 (2013) 146–158, https://doi.org/10.1016/j.enpol.2012.04.030.
[44] F.W. Geels, F. Kern, G. Fuchs, N. Hinderer, G. Kungl, J. Mylan, M. Neukirch, S. Wassermann, The enactment of socio-technical transition pathways: a reformulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990–2014), Res. Policy 45 (2016) 896–913, https://doi.org/10.1016/j.respol.2016.01.015.
[45] D. Rosenbloom, Framing low-carbon pathways: a discursive analysis of contending storylines surrounding the phase-out of coal-fired power in Ontario, Environ. Innov. Soc. Transit. 27 (2018) 129–145, https://doi.org/10.1016/j.eist.2017.11.003.
[46] G. Papachristos, A. Sofianos, E. Adamides, System interactions in socio-technical transitions: extending the multi-level perspective, Environ. Innov. Soc. Transit. 7 (2013) 53–69, https://doi.org/10.1016/j.eist.2013.03.002.
[47] L.-A. Sutherland, S. Peter, L. Zagata, Conceptualising multi-regime interactions: the role of the agriculture sector in renewable energy transitions, Res. Policy 44 (2015) 1543–1554, https://doi.org/10.1016/j.respol.2015.05.013.
[48] C. Wilson, D. Tyfield, Critical perspectives on disruptive innovation and energy transformation, Energy Res. Soc. Sci. 37 (2018) 211–215, https://doi.org/10.1016/j.erss.2017.10.032.
[49] P. Johnstone, P. Kivimaa, Multiple dimensions of disruption, energy transitions and industrial policy, Energy Res. Soc. Sci. 37 (2018) 260–265, https://doi.org/10.1016/j.erss.2017.10.027.
[50] M. Winskel, Beyond the disruption narrative: varieties and ambiguities of energy system change, Energy Res. Soc. Sci. 37 (2018) 232–237, https://doi.org/10.1016/j.erss.2017.10.046.
[51] K.A. Oye, J.H. Maxwell, Self-interest and environmental management, J. Theor. Polit. 6 (1994) 593–624, https://doi.org/10.1177/0951692894006004008.
[52] F. Kern, K.S. Rogge, The pace of governed energy transitions: agency, international dynamics and the global Paris agreement accelerating decarbonisation processes? Energy Res. Soc. Sci. 22 (2016) 13–17, https://doi.org/10.1016/j.erss.2016.08.016.
[53] B.K. Sovacool, F.W. Geels, Further reflections on the temporality of energy transitions: a response to critics, Energy Res. Soc. Sci. 22 (2016) 232–237, https://doi.org/10.1016/j.erss.2016.08.013.
[54] B.K. Sovacool, How long will it take? Conceptualizing the temporal dynamics of energy transitions, Energy Res. Soc. Sci. 13 (2016) 202–215, https://doi.org/10.1016/j.erss.2015.12.020.
[55] Ministry of the Environment and Climate Change, Ontario's Climate Change Strategy, Queen's Printer for Ontario, Toronto, 2015 (Accessed February 6, 2017), https://dr6j45jk9xcmk.cloudfront.net/documents/4928/climate-change-strategy-en.pdf.
[56] C. Bataille, D. Sawyer, N. Melton, Pathways to Deep Decarbonization in Canada, Sustainable Development Solutions Network & Institute for Sustainable Development and International Relations, (2015).
[57] J. Gaede, Ontario, Québec, Electricity and Climate Change: Advancing the Dialogue, HEC Montreal & York University, 2015 (Accessed October 17, 2016), http://sei.info.yorku.ca/files/2013/03/Advancing-the-Dialogue-Final-Report-071415-Translated-1.pdf.
[58] M.B. Amor, P.-O. Pineau, C. Gaudreault, R. Samson, Electricity trade and GHG emissions: assessment of Quebec's hydropower in the Northeastern American market (2006–2008), Energy Policy 39 (2011) 1711–1721, https://doi.org/10.1016/j.enpol.2011.01.001.
[59] Air Ontario Clean, Alliance, Powering Smart Action on Climate in Ontario, OCAA, Toronto, 2017 (Accessed October 13, 2018), http://www.cleanairalliance.org/wp-content/uploads/2017/06/climate-plan-2.pdf.
[60] Ontario Ministry of Energy, Delivering Fairness and Choice: Ontario's Long-term Energy Plan, Queen's Printer for Ontario, Toronto, 2017.
[61] F. Kern, The discursive politics of governing transitions towards sustainability: the UK Carbon Trust, Int. J. Sustain. Dev. 15 (2012) 90–106.
[62] M. Winfield, Blue-green Province: the Environment and the Political Economy of Ontario, UBC Press, Vancouver, 2012.
[63] Navigant, Fuels Technical Report, Navigant Consulting, Inc., Toronto, 2016.
[64] Ontario Ministry of Finance, Ontario Fact Sheet: October 2017, Gov. Ont., 2017 (Accessed November 15, 2017), https://www.fin.gov.on.ca/en/economy/ecupdates/factsheet.html.
[65] Ontario Ministry of the Environment and Climate Change, Ontario's Five Year Climate Change Action Plan: 2016–2020, Queen's Printer for Ontario, Toronto, 2016.
[66] M. Winfield, Ford's ideological energy agenda putting Ontario on a shaky path, Hamilt. Spect. (2018) (Accessed August 16, 2018), https://www.thespec.com/opinion-story/8766237-ford-s-ideological-energy-agenda-putting-ontario-on-a-shaky-path/.
[67] A. Sharp, Doug Ford says he will "come down heavy" on polluters, but offers few details, Natl. Obs. (2018) (Accessed June 29, 2018), https://www.nationalobserver.com/2018/06/02/news/doug-ford-says-he-will-come-down-heavy-polluters-offers-few-details.
[68] Legislative Assembly of Ontario, Hansard 17-JUL-2018_L004, OLA, 2018 (Accessed August 16, 2018), https://www.ola.org/en/legislative-business/house-documents/parliament-42/session-1/2018-07-17/hansard.
[69] M. Fitzpatrick, Doug Ford's Environmental Policies Light on Details, Advocates Say, CBC, 2018 (Accessed July 5, 2018), https://www.cbc.ca/news/canada/doug-ford-s-environmental-policies-light-on-details-advocates-say-1.4703078.
[70] M. Winfield, Doug Ford's Energy Shake-up Could Cost Ontario, The Conversation, (2018) (Accessed August 16, 2018), http://theconversation.com/doug-fords-energy-shake-up-could-cost-ontario-100436.
[71] Environment and Climate Change Canada, Pan-canadian Framework on Clean Growth and Climate Change: Canada's Plan to Address Climate Change and Grow the Economy, Government of Canada, Ottawa, 2016 (Accessed July 2, 2017), http://epe.lac-bac.gc.ca/100/201/301/weekly_acquisitions_list-ef/2017/17-01/publications.gc.ca/collections/collection_2017/eccc/En4-294-2016-eng.pdf.
[72] Environmental Commissioner of Ontario, Surplus Baseload Electricity Generation in Ontario, ECO, 2017 (Accessed August 20, 2018), https://eco.on.ca/blog/surplus-baseload-electricity-generation-in-ontario/.
[73] Statistics Canada, Households and the Environment: Energy Use, Government of Canada, Ottawa, 2013 (Accessed October 30, 2017), http://www.statcan.gc.ca/pub/11-526-s/11-526-s2013002-eng.pdf.
[74] K. Cryderman, J. Lewis, Wynne Steps Back From Plan to Phase Out Natural Gas in Ontario, Globe Mail, 2016 (Accessed July 3, 2017), https://www.theglobeandmail.com/news/national/wynne-steps-back-from-plan-to-phase-out-natural-gas-in-ontario/article30182423/.
[75] A. Morrow, G. Keenan, Ontario to Spend $7-Billion on Sweeping Climate Change Plan, Globe Mail, 2016 (Accessed December 9, 2017), https://www.theglobeandmail.com/news/national/ontario-to-spend-7-billion-in-sweeping-climate-change-plan/article30029081/.
[76] Government of Ontario, Expanding Natural Gas to More Communities Across Ontario, Ont. Newsroom, 2017 (Accessed December 12, 2017), https://news.ontario.ca/moi/en/2017/01/expanding-natural-gas-to-more-communities-across-ontario.html.
[77] Statistics Canada, Motor Vehicle Registrations, by Province and Territory, Gov. Can., 2017 (Accessed November 17, 2017), https://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/trade14b-eng.htm.
[78] E. Schmidt, Electric Vehicle Sales in Canada: Q1 2017, Fleetcarma, 2017 (Accessed October 30, 2017), https://www.fleetcarma.com/electric-vehicle-sales-canada-q1-2017/.
[79] Statistics Canada, Sales of Fuel Used for Road Motor Vehicles, by Province and Territory, Gov. Can., 2017 (Accessed November 17, 2017), https://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/trade37b-eng.htm.
[80] G. Mordue, Electricity prices and industrial competitiveness: a case study of final assembly automobile manufacturing in the United States and Canada, Energy Policy 111 (2017) 32–40, https://doi.org/10.1016/j.enpol.2017.09.008.
[81] Bruce Power, L.P. Bruce Power (Ed.), Long-Term Energy Plan Submission, 2016 Tiverton.
[82] D. Mackinnon, RE: Ontario's 2017 Long-Term Energy Plan, Power Workers' Union, Toronto (2016).

[83] Association of Power Producers of Ontario, APPrO Submission on Long-term Energy Plan and Ontario Planning Outlook, APPrO, Toronto, 2016.
[84] Canadian Nuclear Association, Comments on Ontario's Long-term Energy Plan, CNA, Ottawa, 2016.
[85] Canadian Solar Industries Association, The Role of Solar in Ontario's Long Term Energy Plan, CanSIA, Ottawa, 2016.
[86] Canadian Wind Energy Association, Canadian Wind Energy Association Submission to the Ontario Long-term Energy Plan Review, CanWEA, Ottawa, 2016.
[87] Clean Energy Canada, Submission: Planning Ontario's Energy Future: a Discussion Guide to Start the Conversation, CEC, Vancouver, 2016.
[88] David Suzuki Foundation, David Suzuki Foundation Input on Ontario's Long-term Energy Plan, DSF, Toronto, 2016.
[89] Ontario Society of Professional Engineers, the Ontario Society of Professional Engineers' Submission for Ontario's 2017 Long-term Energy Plan, OSPE, Toronto, 2016.
[90] Enbridge Gas, Role of the Natural Gas Grid in Our Low-Carbon Future, (2016) Toronto.
[91] Ontario Power Generation, Power With Purpose: Ontario Power Generation's Long-term Energy Plan Submission, OPG, Toronto, 2016.
[92] W. Urban, Biomethane injection into natural gas networks, in: A. Wellinger, J. Murphy, D. Baxter (Eds.), Biogas Handb. Woodhead Publishing, 2013, pp. 378–403, , https://doi.org/10.1533/9780857097415.3.378.
[93] Ontario Energy Association, Development of the 2017 Long-term Energy Plan: Planning for a Low Carbon, Resilient, and Affordable Future for Ontario, OEA, Toronto, 2016.
[94] Ontario Federation of Agriculture, LTEP Policy for Natural Gas and Electricity, OFA, Guelph, 2016.
[95] Greater Sudbury Chamber of Commerce, Timmins Chamber of Commerce, Thunder Bay Chamber of Commerce, North Bay & District Chamber of Commerce, Sault Ste. Marie Chamber of Commerce, Northern chambers long-term energy plan submission, Northern Chambers of Commerce, 2016.
[96] Independent Electricity System Operator, Ontario Planning Outlook: A Technical Report on the Electricity System Prepared by the IESO, IESO, Toronto, 2016.
[97] Hydro-Quebec Energy Marketing Inc. Comments of HQ Energy Marketing Inc. On the Ontario Planning Outlook, (2016) HQ, Montreal.
[98] D. Saxe, Developing the 2017 Long-term Energy Plan: A Special Report to the Legislative Assembly of Ontario, Environmental Commissioner of Ontario, Toronto (2016).
[99] A. Jones, Ontario Energy Minister Says Hydro Negotiations With Quebec Still Underway, Can. Press Tor. (2017) (Accessed November 20, 2017), https://search.proquest.com/docview/1927675256/citation/A043F8C622B84495PQ/1.
[100] Canada NewsWire, Study Finds Increased Electricity Imports From Quebec an Expensive Option for Ontario, CNW Group, 2016 (Accessed November 20, 2017), https://search.proquest.com/docview/1803441453/abstract/16D58500F02041EDPQ/1.
[101] Canada NewsWire, End Secret Power Deals, Say Energy Professionals, CNW Group, 2017 (Accessed November 20, 2017), https://search.proquest.com/docview/1927004479/citation/468C934D9994C99PQ/1.
[102] Air Resources Board, Zero-emission Vehicle Standards for 2009 Through 2017 Model Year Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles, California Environmental Protection Agency, Sacramento, 2016 (Accessed December 4, 2017), https://www.arb.ca.gov/msprog/zevprog/zevregs/1962.1_Clean.pdf.
[103] A. Petroff, These Countries Want to Ban Gas and Diesel Cars, CNN Money, 2017 (Accessed November 17, 2017), http://money.cnn.com/2017/09/11/autos/countries-banning-diesel-gas-cars/index.html.
[104] J. Arbib, T. Seba, Rethinking transportation 2020-2030, RethinkX (2017).
[105] International Organization of Motor Vehicle Manufacturers, 2017 Production Statistics, OICA, 2018 (Accessed August 21, 2018), http://www.oica.net/category/production-statistics/2017-statistics/.
[106] M.A. Hajer, The Politics of Environmental Discourse: Ecological Modernization and the Policy Process, Clarendon Press, 1995.
[107] Ontario Clean Air Alliance, Power Choices, OCAA, Toronto, 2016 (Accessed October 13, 2016), http://www.cleanairalliance.org/wp-content/uploads/2016/06/vision-june7.pdf.