Energy Policy 107 (2017) 11–26

Contents lists available at ScienceDirect

Energy Policy

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

Transition and transformation: A review of the concept of change in the progress towards future sustainable energy systems

Michael Child*, Christian Breyer

Lappeenranta University of Technology, Skinnarilankatu 34, 53850, Lappeenranta, Finland

ARTICLE INFO

Keywords:
Energy system change
Transition
Transformation
Multi-level perspective
Socio-technical system

ABSTRACT

It seems generally accepted that change will occur in global energy systems. There also appears to be consensus on the kinds of changes that may possible for the future, even though there may be disagreement over the exact mix of technologies and policies needed to increase sustainability or mitigate climate change. The terms transition and transformation have both been used to denote the type of change needed in large socio-technical systems. However, the terms have been used both in contradiction of each other and synonymously by different authors. A comprehensive review of both theory and usage in scientific publications was conducted to determine if the terms have been used to denote fundamentally different concepts and if the concept of change is framed differently by usage so as to affect understanding. Despite two camps being readily identifiable, it was concluded that the terms generally refer to the same fundamental concept. At the same time, framing of the concept can be viewed as somewhat different, resulting in a potential for confusion on the part of the reader that may detract from achieving the outcome of change. It is suggested that change to physical forms and systems be denoted as transformations, and that changes to large socio-technical systems be denoted as transitions when the focus is on a higher order of change that highlights the ways that society motivates, facilitates, and benefits from change.

1. Introduction

Global energy systems constantly evolve in response to a myriad of drivers. At the moment, and likely well into the future, the key drivers appear to be mitigating climate change, strengthening energy security, ensuring economic competitiveness, providing social justice, reducing energy poverty, and stimulating technological innovation. With such strong forces of change, and the possibility of yet unforeseen disruptive technological advances or other game changers, it seems obvious that energy systems of the future may be very different from those today. However, the nature, speed and degree of change remains elusive, at least in its description and denotation. At the heart of the matter appears to be whether the change should be referred to as a transition, or a transformation. The expressions *energy system transition* and *energy system transformation* are commonly used to denote the change, but there appears to be some confusion over the actual meanings of these expressions.

A cursory view of popular definitions of the words denoting change in energy systems is shown in Table 1. From these definitions, it appears that the word *transition* infers slightly more focus on the process or period of change, whereas *transformation* infers more focus on the magnitude, significance, or result of the change. This difference is seen in the following abstract, which uses both expressions (underlined).

> ***The paper highlights the energy dilemma in China's modernization process. It explores the technological and policy options for the transition to a sustainable energy system in China with Tsinghua University's Low Carbon Energy Model (LCEM). China has already taken intensive efforts to promote research, development, demonstration and commercialization of sustainable energy technologies over the past five year. The policy actions cover binding energy conservation and environmental pollution control targets, economic incentives for sustainable energy, and public R & D supports. In order to achieve the sustainable energy system transformation eventually, however, China needs to take further actions such as strengthening R & D of radically innovative sustainable energy technologies and systems such as poly-generation, enhancing the domestic manufacturing capacity of sustainable energy technologies and systems, creating stronger economic incentives for research, development, demonstration and commercialization of sustainable energy technologies, and playing a leading role in interna-***

* Corresponding author.
E-mail address: Michael.Child@lut.fi (M. Child).

http://dx.doi.org/10.1016/j.enpol.2017.04.022
Received 10 January 2017; Received in revised form 7 April 2017; Accepted 11 April 2017
Available online 19 April 2017

Table 1
Definitions from common online dictionaries.

Dictionary	Transition	Transformation
Oxford University Press	***the process or a period of changing from one state or condition to another***	***a marked change in form, nature, or appearance***
Cambridge University Press	***a change from one form or type to another, or the process by which this happens***	***a complete change in the appearance or character of something or someone, especially so that thing or person is improved***
Merriam-Webster (2015)	***a change from one state or condition to another***	***a complete or major change in someone's or something's appearance, form, etc.***
Wiktionary	***the process of change from one form, state, style or place to another***	***a marked change in appearance or character, especially one for the better***

tional technology collaborations (Chai and Zhang, 2010).

Here the word *transition* is used close to the word *process*. By contrast, *transformation* is used later in the paragraph to denote what China ultimately strives *to achieve* after the process is over. However, definitions of words are only part of the analysis. Further insights should be gained from both the frequency of use and the communicative intention of the people using such expressions. The frequency of each expression was examined by seeing the number of hits they would receive from common academic and general search engines (Table 2).

It appears that in both academic and general usage, *energy system transformation* appears somewhat more frequently as a phrase, even when describing the same concept of change. This begs the question of what may be the underlying illocutionary force, or intention of producing one versus the other in speech or in writing. For example, a simple expression such as *I am cold* can have different illocutionary forces depending on the context. It could be a simple statement of fact, an answer to a question, or a directive to close a window. Similarly, two expressions such as *I am cold* and *Please close the window* could have the exact same illocutionary force (a request to close a window) yet quite different morphological forms.

Fairclough and Wodak (1997) discuss how linguistic factors (in addition to semiotic and interdiscursive features) can influence and be influenced by society. Words, grammar, organizational structures, etc. can shape societal values, attitudes and behaviours by framing issues and problems in a certain respect so as to highlight various levels of problem recognition, the degree of change needed, underlying actions needed and obstacles along the path of change. These linguistic factors represent a discourse, or “a shared way of apprehending the world”. Further, different discourses can shape the acceptability of various alternatives of change, such as promoting one alternative over another. In extreme cases, not promoting one or more alternatives can be the result of hegemonic power in society. This is typical of systems that either do not tolerate or do not need change, especially radical change. Importantly, Fairclough and Wodak (1997) argue that words or expressions that are used to convey concepts, representations or future realities should not always be taken at face value as they “are themselves elements of discourses which are associated with particular strategies for change”.

Table 2
Frequency of use of expressions. The search was performed in June, 2015.

Expression	SCOPUS	ScienceDirect	Google Scholar	Google
Energy system transition	34	98	306	6920
Energy system transformation	27	108	915	10200

In particular, Fairclough and Wodak (1997) commented on the use of the words transition and transformation in the context of the climate change agenda. In this work, a transition was defined as “passage from a well-known defined point of departure to a unitary and well-defined destination”. In terms of efforts related to social change, using the word transition was “difficult to reconcile with the complexity and diversity of the processes which are actually taking place”. Fairclough and Wodak (1997) then cite other authors (Stark and Bruszt, 1998) who prefer *transformation* in such cases.

Insights into the concept of change can also be gathered from the field of Natural Science, particularly from the seminal writings of Stephen J. Gould (Eldredge and Gould, 1972; Gould, 1977), who argued that evolutionary change in species did not happen through slow, gradual change (phyletic gradualism), but by discontinuous breaks and jumps followed by long periods of stability (punctuated equilibria). Accordingly, phyletic gradualism was described as process of slow, steady, directional transformation from one morphological form to another. On the other hand, punctuated equilibria were characterized as long periods of stability in the fossil record broken sharply by rapid, divergent, discontinuous, and abrupt transitions (Gould, 1977).

In the field of Futures Research, the word *transformation* has been reserved for a change in human society that is quite unique. As one of the “four generic futures” that govern future scenario development (the others are continued growth, collapse, and discipline), a transformation occurs through the power of new or innovative niche technology that anticipates “a change from its present form into a new ‘posthuman’ form, on an entirely artificial Earth”, thereby creating a so-called “dream society” (Dator, 2009). In this sense, transformational scenarios are not only much less likely, but often viewed as being highly radical in their nature. They are inherently different from, and perhaps opposite to, business as usual. As such, the end state appears fundamentally different from the starting state.

From the field of economics, seminal work by Polanyi (1944) outlined the rise of the current market economy, which he dubbed *The Great Transformation*. Polanyi describes how the evolution of modern nation states forced changes in both social structures and human nature which in turn created favourable conditions for capitalism. Implied in this account is that relationships among societal actors and the norms they follow underwent major reorganization to produce a new social order and way of life. In this case, social-based regulatory systems were replaced by self-regulating markets. In this new world order, nothing new or innovative was created, as market-based economic activities were already in place for commodities that were either rare or traded over long distances, nor was anything destroyed outright – social-based regulation still exists in some areas. The change involved a redirection of the system whereby the new system evolved out of the old.

Recent work related to sustainable development and mitigation of climate change shows confusion in naming what is happening to modern energy systems. On the one hand, there are those who claim a Great Transition is needed (Boulding, 1964; Daily and Walker, 2000; Jorgenson, 1986; Lieberthal and Lieberthal, 2003; Raskin et al., 2002). Common within each is how *transition* is defined. In general, it is seen as a paradigm shift that "would challenge both the viability and desirability of conventional values, economic structures and social arrangements" (Lieberthal and Lieberthal, 2003). There also appears to be mention of some kind of evolution to a higher or better state of being. Change is seen as structural and not at all incremental, representing a discontinuity in historical trajectory that may appear either idealistic or improbable from current perspectives. In fact, these recent works describe change in a very similar way to Polanyi (1944) albeit with a different outcome. In this case, the self-regulating markets would be constrained by social, cultural or environmental goals. However, the magnitude and mechanisms of change appear similar.

In the context of the dynamics of change in socio-technical systems, researchers have defined three separate typologies of change processes involving a multi-level perspective (Geels, 2002, 2007, Geels and Kemp, 2007). The macro elements of a socio-technical system (or landscape) involve the exogenous environment that encompasses the system. These elements are rather rigid by nature and represent strong tendencies of a system, such as cultural icons, forms of government, environmental values, geographic arrangements of cities, or large-scale infrastructures (e.g. electricity systems, railroads, highway systems, or telephone networks). However, such elements are susceptible to occasional change due to significant events such as major shifts in public opinion, challenges of previously held assumptions of how the world works, scientific discovery, or influence from outside the system (e.g. war, pestilence, poverty, drought, disaster, embargo, etc.). The meso elements comprise the socio-technical regime, and include dominant technologies, actors and social groups (engineers, corporations, scientists, consumers, policy-makers, special-interest groups, etc.), and the rules that guide perceptions and activities. These rules can be formal (standards, laws, targets, regulations, etc.), normative (beliefs, behavioural norms, identities, roles, etc.), or cognitive (guiding principles, corporate values, rules of thumb, agendas, etc.) (Geels, 2007). The meso social agents and norms "maintain and refine the elements" of the technical system (Geels, 2007). The micro level is comprised of an abundance of relatively independent niche actors, technological innovations, radical novelties, or fringe activities (ibid.). This micro level is often enabled or subsidized by the mainstream regime actors as pilot or demonstration projects, but can often be the result of independent invention or development.

The three change processes identified were reproduction, transition, and transformation (Geels, 2002). Reproduction involves incremental, cumulative, almost invisible changes to the socio-technical regime without any fundamental change in the overall socio-technical landscape. In this case, significant innovation is rare or has little impact. The system in question is in a state of dynamic stability. It may also be possible that a lack of change is the result of strong vested interests that exercise hegemonic power, such as monopolies.

A transformation occurs when "changes at the landscape level create pressure on the regime, leading to re-orientation of the direction of innovative activities" (Geels and Kemp, 2007). The changes in the socio-technical landscape involve challenges of "previously held assumptions and place new issues on the problem agenda". In such a change dynamic, incumbent actors survive through negotiation, struggle or shifting alliances, usually after rejecting the need for transformation for as long as possible. Often, transformation is initiated by the identification of a previously unknown or unaccounted negative externality which causes the initial challenge to the *status quo*. The result is "a new system may grow out of the old one, through cumulative adjustments in a new direction". As an example, the authors offer the transformation of waste management activities in the Netherlands from one that was based on uncontrolled landfilling to one that involves recycling, incineration, reuse and controlled landfilling (Geels and Kemp, 2007). In other work, Geels argues that transformation is the most likely process of change in Large Technical Systems that tend to have relatively high momentum "as result of stabilizing connections between technology and society" (Geels, 2007), such as energy systems.

Lastly, a transition occurs when new, innovative changes break through into the mainstream socio-technical landscape so as to change both the trajectory of the landscape and lead to the creative destruction of some or all of the actors within the socio-technical regime. In this case, developments in the landscape cause a need for a reaction by the regime actors, who are subsequently unable to respond well enough. Thereby, a window of opportunity is open for one or more innovations that are ultimately accepted by a new social order. The example given by the authors is of the transition from transportation by horse and carriage to a system based on cars. In this case, the system does not find a new direction, but a completely new system trajectory is established (Geels and Kemp, 2007). A more modern example may be the transition from fixed-line to mobile telephone systems.

In a similar vein, Roggema et al. (2012) define the same three terms. Firstly, incremental change is defined as "a slow process, which modifies the landscape only slightly". Second, a transition is "a gradual, continuous process of societal change, changing the character of society (or a complex part) structurally" in response to a crisis or chaos that shifts a system from one form to another (weaker to stronger) and establishes a new state of stability. Thirdly, a transformation is "the capacity to transform the stability landscape itself in order to become a different kind of system, to create a fundamentally new system when ecological, economic, or social structures make the existing system untenable". In this regard, transformation is seen as "disconnected processes of growth".

Later, Geels and Schot (2007), Verbong and Geels (2010), and Geels (2012) redefined and reclassified the terms they used based on the timing and nature of different multi-level interactions. As such, a transition was redefined as a change "from one sociotechnical regime to another". Moreover, different transition pathways were identified: transformation, reconfiguration, technological substitution, and de-alignment/re-alignment. So, a transformation became a typology of transition rather than a separate change process. No change was made to the earlier definition of transformation, but a transition became a higher order, more general change process. The process of reproduction remained as a non-change process that reflected "gradual adjustment and reorientation of existing regimes".

In German, there is a single named concept – *Energiewende* – that has a universally understood meaning which has served as a rallying cry for change in energy systems. The concept was introduced by the Öko-Institut (Krause et al., 1980), an ecologically oriented research institute, which applied the ground-breaking work of Lovins (1977) on the final energy target of a fully renewable energy based system to the German context. Although precise translations can be debated, *Wende* denotes several dimensions, such as a change, turning point, switch-over, rebound, reversal, tacking, and even revolution, finally suggesting a new direction or trajectory. However, the term is commonly used for the kind of peaceful revolution that has resulted in such dramatic socio-political change as the destruction of the Berlin Wall and the reunification of the country. Whether one is an opponent or proponent of the changes, methods or goals proposed, there is at least a broad understanding of what the concept means, which allows for easier discourse around the concept. The German word, *Energiewende*, began appearing in leading English language media in April, 2011, and several translations have been offered (Hockenos, 2012). Such a concept is needed in English to reflect the magnitude and importance of change, but exactly which it should be, *transition* or *transformation*, is currently unclear.

Schmid et al. (2017) found that there may indeed be conflicting visions related to representations of a 'desirable' future energy system and the means by which to realize it. Further, they suggest that different mental models, worldviews, narratives, or storylines can frame competing concepts of a future energy system by "simplifying complex situations into chains of events and contain elements such as a protagonist and a challenge". Essentially, an internal representation of a concept provides an individual or group with a shared way "to interpret the environment, to reason and to make decisions". Their findings conclude that open acknowledgement of worldviews that underlie different visions of change "is the elephant in the room of energy policy debates". Such acknowledgement may be one method of overcoming future political stalemate, and conflict between challenger actors and energy system incumbents. One such worldview is a focus on the technologies and economic elements that comprise future energy systems. The other is a complementary framework that conceptualizes change in energy systems also as a collection of broader social endeavors.

Chappin and Ligtvoet (2014) examined the use of *transition* and *transformation*, finding that the choice of one term or another was determined mainly by networks and clusters of "directly and indirectly cooperating authors" who "repeatedly write together and cite each other's work". The research indicated that the larger cluster around the usage of *transition* was more likely related to existing networks, (e.g. the Sustainability Transition Research Network), geography (i.e., around the Netherlands), or co-authors than the product of two distinct schools of thought related to the dynamics of change. At the same time, there was a suggestion that, in the context of energy systems, *transition* authors tend to highlight societal contributions and impacts, while *transformation* authors tend to take "a more descriptive stance". However, the study cautions that this difference "does not necessarily imply less impact". Chappin and Ligtvoet (2014) also caution that their bibliometric analysis should be enriched by more systematic and detailed explorations of the terms. To this end, the study clearly indicated what different terms were being used by different groups, and the influence of clusters of existing networks, but took little accounting of what various authors intended to mean. Nor did this study examine the specific context of change in energy systems. Only by doing so can one determine if fundamentally different discourses exist that frame the concept of change needed in energy systems.

Therefore, the purpose of this work is to review how each word is being used in relation to changes to energy systems in scientific literature and to attempt to devise a recommendation for future use. To do this, a systematic review of the usage of each word in recent journal publications was performed in addition to consideration of how the authors intended the word to be understood (either directly or indirectly). Accordingly, two main questions guided this work. Firstly, do the words *transition* and *transformation* represent fundamentally different concepts in the scientific literature? And secondly, are the expressions used in such a way as to frame the concept of change in a different way, so as to highlight various levels of problem recognition, the degree of change needed, underlying actions needed and obstacles along the path of change? The answers to these questions are then followed by general conclusions on findings and recommendations for future use of the terms.

2. Methodology

In the first part of this analysis, scientific publications were chosen that dealt with the topics of energy system transitions and energy system transformations. Journal articles were selected during the first week of June, 2015 in the following manner. Using ScienceDirect, an advanced search was performed for scientific publications that contained both the expressions "energy system transition" and "energy system transformation" within all search fields. Articles were rejected if one of the search expressions was found only in the references. The final list included 12 publications. Next, an advanced search was made using just the expression "energy system transition" within the abstract, title or keywords. If the publication was found in the previous category, it was not included. One publication was not available for free to the Lappeenranta University of Technology library and was rejected. Articles were also rejected if the expression only occurred in the references section of the publication and not specifically used in the text. The final total for this category was 16 publications. Using the same criteria for the expression "energy system transformation", 13 publications were selected. All publications used in this study are listed in Table 4.

Next, a series of questions was devised that explore various aspects of meaning related to the words *transition* and *transformation*. These questions were mostly based on characteristics gleaned from the Introduction above. Table 3 introduces each question and the sub-questions used to determine answers. Each question was answered after the careful reading of the scientific publications. Furthermore, answers to questions were based on explicit use of words or expressions in the Title or Abstract of each article. It was assumed that language use in these sections of the publications would be representative of the text as a whole. Moreover, these sections were deemed sufficient linguistic context to acquire the general intention of meaning or description necessary for further analysis. In two cases when an Abstract was not available (Huberty and Zysman, 2010; van Vuuren et al., 2012), the first paragraph of the introduction was used. The keywords for each article were also compiled to determine if the intended topics of the articles differed in nature. Results were then compiled, tabulated and analyzed. In many cases, answers to key questions were not easily discerned. This explains the lack of reporting for some individual articles in Tables A1–A3. Results were then analyzed in terms of a variety of semantic features that may be present, especially any that elicit positive or negative connotations.

Table 3
Key questions and sub-questions applied to each article.

Key question	Sub-questions
What words are used to define or describe change?	What is the speed or time frame? How forced or natural is the change? Is it described as radical or fundamental? How serious is the problem?
How will change proceed?	Is it continuous or discontinuous? Is it gradual or punctuated? How desirable or undesirable is it? What specific words are used to denote change? What degree of effort is necessary? What is the consequence of inaction?
What are the barriers to change?	How are barriers denoted? What is the source of barriers?
Who or what are the agents or facilitators of change?	What people, policies or institutions are involved in enabling change? What spheres of life do the agents come from (social, environmental, economic, or technological)? What is the motivation of change?
What is the outcome of change?	Is there a well-defined goal or target? Is the outcome restricted over time or space? Are there mention of alternative outcomes?

Table 4
List of publications used in this review.

Transition articles	Transition/transformation articles	Transformation articles
Lachman, 2014	Demski et al., 2015	Huberty and Zysman, 2010
Miller et al., 2015	Chai and Zhang, 2010	Jacobsson and Lauber, 2006
Schubert et al., 2015	Muench et al., 2014	Ydersbond, 2014
Diaz-Rainey and Tzavara, 2012	Eom et al., 2015	Marcucci and Fragkos, 2015
Peter Andreasen and Sovacool, 2014	Butler et al., 2015	Chowdhury et al., 2014
Parag and Janda, 2014	Bertram et al., 2015	Bădileanu, 2014
Zhang et al., 2010	Pfenninger and Keirstead, 2015	Sano et al., 2015
Momirlan and Veziroglu, 2005	Winskel et al., 2014	Gambhir et al., 2013
Morlet and Keirstead, 2013	Nilsson et al., 2011	Delina, 2012
Hall and Foxon, 2014	Eyre and Baruah, 2015	Capros et al., 2014
Rutter and Keirstead, 2012	Yuan et al., 2012	van Vuuren et al., 2012
McDowall, 2012	Späth and Rohracher, 2010	Pregger et al., 2013
Hong et al., 2013a		Stenzel and Frenzel, 2008
Hong et al., 2013b		
Foxon et al., 2013		
Hugh et al., 2007		

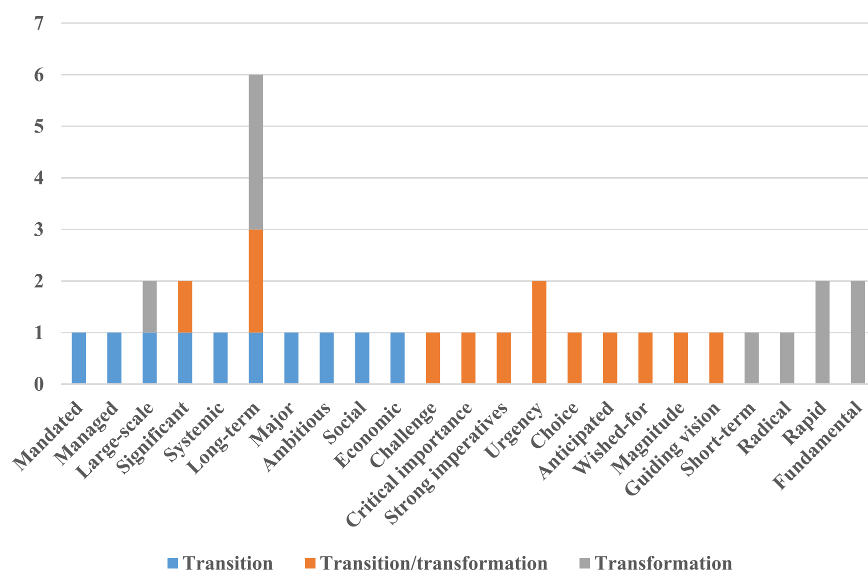

Fig. 1. Frequency of selected words used to describe change in different article types.

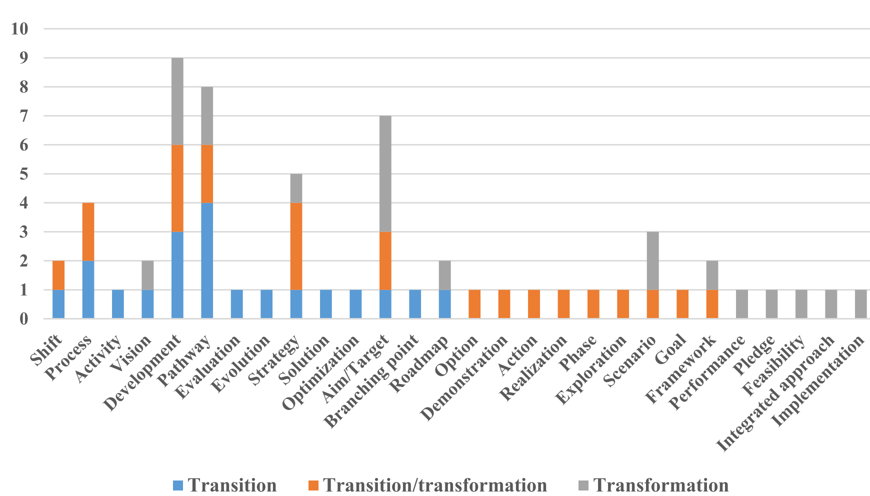

Fig. 2. Frequency of selected words used to describe how change proceeds in different article types.

3. Results

Table A1 (Appendix A) shows the results related to the general representation of change. A smaller collection of selected words used to define or describe change and their frequency are shown as a summary in Fig. 1. In each of the article types, change appears to be denoted as a large-scale and long-term process. However, transformation and transition/transformation articles may also focus on the short term and highlight a faster speed at which change should take place. In addition, transformation articles show a tendency to highlight the fundamental or systematic nature

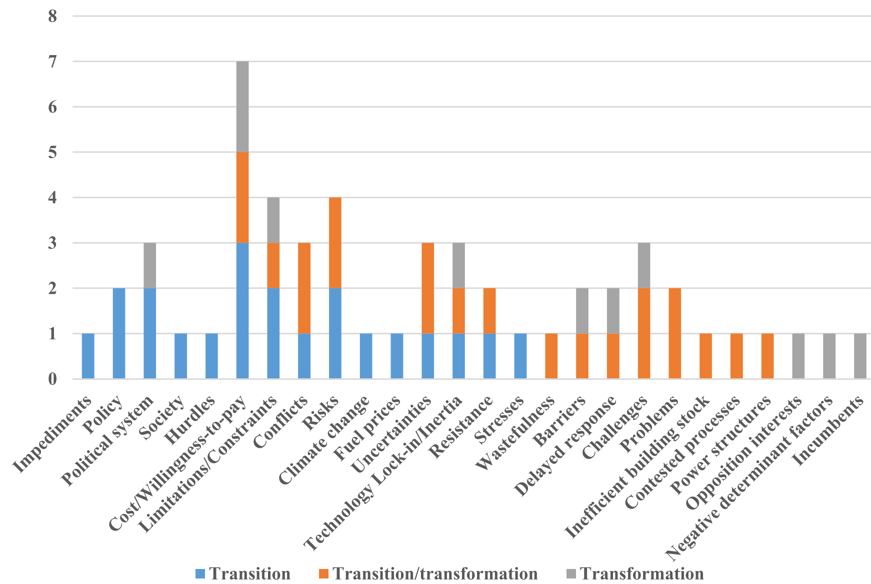

Fig. 3. Frequency of selected words used to describe barriers to change in different article types.

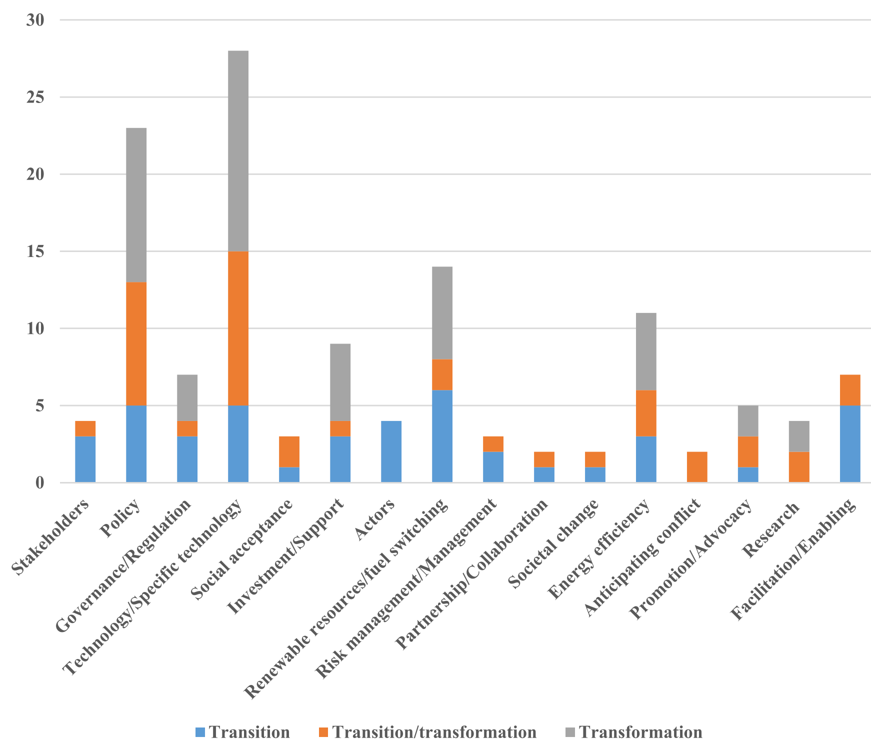

Fig. 4. Frequency of selected words used to denote agents of change in different article types.

of change. Alternatively, transition and transition/transformation articles tend to show the social or emotional aspects of change by highlighting the significance, urgency, anticipation or ambitiousness of change. At the same time, there are exceptions to this general trend with transition articles, with one article referring to change as something that is mandated and managed. One could, however, infer an orderly social, economic or political control of change from the use of such terms.

Table A2 (Appendix A) show the results related to the key question of how change is described as proceeding. A smaller collection of selected words used to describe change how change will proceed and their frequency are shown as a summary in Fig. 2. In very many cases, change is described as a result of developments or processes which proceed along pathways toward targets. Quite often, there appears mention of roadmaps, frameworks or strategies. In this regard, change appears to be orderly and the result of intentional, premeditated actions that are the result of informed choices or options. As such, there appears to be no significant difference between the different article types.

Table A3 (Appendix A) shows results related to the denotation of barriers in different article types. A smaller collection of selected words used to denote barriers and their frequency are shown as a summary in Fig. 3. In general, word choice in transformation articles appear to be more moderate, reflecting a neutral impression of the barrier. There is reluctance, opposition interests, challenges, limitations or effects. By extension, one could infer that the barrier itself is more manageable, is easier to overcome, or can somehow be avoided. In contrast, transition and transition/transformation articles again show rather negative emotional connotations by utilizing words such as conflict, risk, cost, resistance, power, or stress. In only one case (Capros et al., 2014) did a

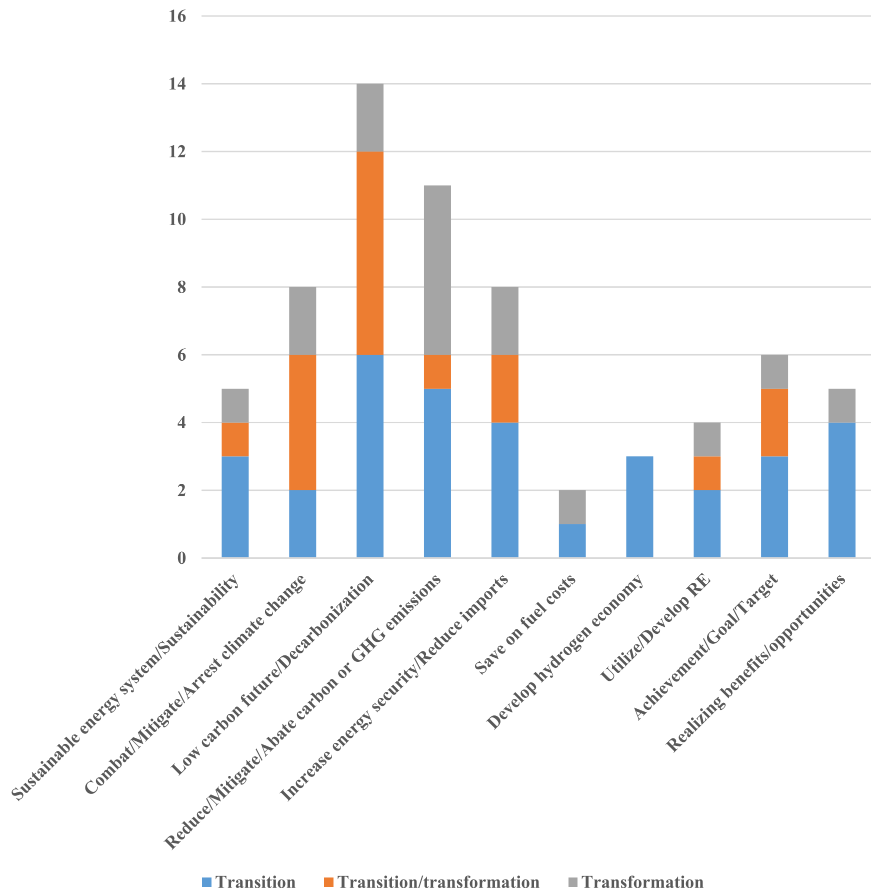

Fig. 5. Frequency of selected words used to denote the outcome of change in different article types.

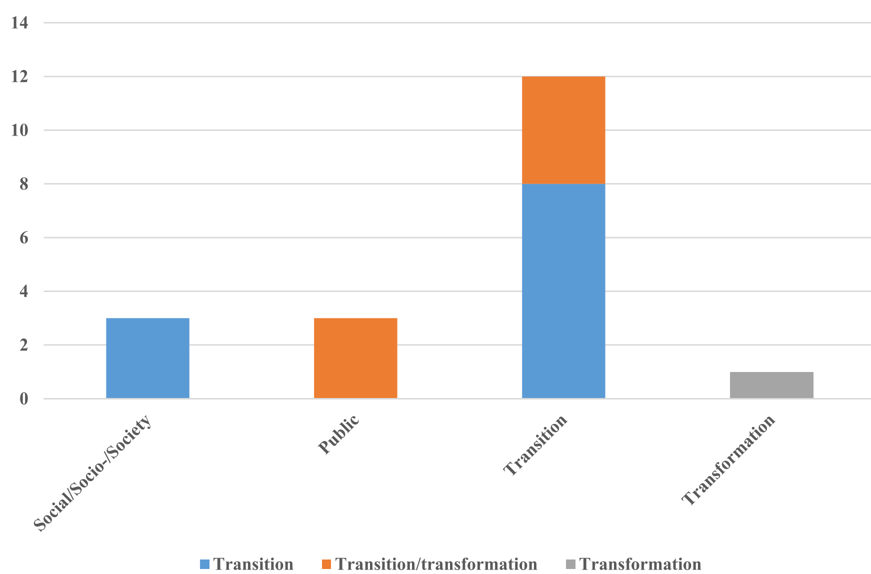

Fig. 6. Frequency of selected words used as keywords in different article types.

transformation article show strong emotional connotations, with the expression "significant adverse effects".

Table A4 (Appendix A) shows results related to the agents of change. A smaller collection of selected words used to denote agents of change and their frequency are shown as a summary in Fig. 4. In most cases, such agents are denoted as technologies (both specific and general), policies, measures, efforts or incentives. In many cases, energy efficiency is named directly as a facilitator of change. In a great majority of instances, governance and institutional support are highlighted. In only one way do the different article types appear to differ to some extent. Transition article may show a tendency to also denote agents in human terms, such as actors, stakeholders, and partners. This slightly increased humanization appears to go hand in hand with the trend to show the social aspects of change as seen in the previous Tables A1 and A2.

Table A5 (Appendix A) shows results related to the outcome of change. A smaller collection of selected words used to denote the outcomes of change and their frequency are shown as a summary in Fig. 5. While some articles show very concise outcomes related to the diffusion of specific technologies or achievements in specific regions or countries, in general outcomes are rather consistent for each of the article types. These outcomes tend to involve creating a sustainable energy system, mitigating climate change, reducing or eliminating carbon emissions, and increasing the utilization of renewable energy. To some extent, however, transition articles show a wider range of outcomes, many of which fall into the social realm, such as reduction of import dependencies, a cleaner planet, enhanced energy security, lower fuel prices and meeting energy demands. This is combined with greater mention of general outcomes, such as goals, targets, benefits and opportunities.

Table A6 (Appendix A) shows results related to key words used. A smaller collection of selected words used as keywords and their frequency are shown as a summary in Fig. 6. In general, there is a wide range of terms used as key words, suggesting that authors are making some attempts at individuality. As expected, energy systems are often specifically mentioned as key words, as are agents of change and outcomes. Technology is often named, as are institutions and policies. However, to a degree in transition articles, there is also mention of words or phrases related to social life. This also happens to a lesser degree in transition/transformation articles. This is seen in such key words as socio-technical systems, socio-energy system, society, social acceptance, willingness-to-pay, green consumerism, critical stakeholder analysis, actors, public policy, public acceptability, and public perception. There is no such mention of public or social terms in the key words of transformation articles.

In summary, there appears to be a slight difference in how the different article types use language to denote change in energy systems. In transition articles, and to some extent transition/transformation articles, there appears to be more focus on the social elements of change and the outcomes of change from a social perspective. At the same time, there are still great consistencies with how change is represented independent of the article type, as each involves denotations of the technologies, resources, policies and pathways of change as well as consistency in representing the outcomes of change.

4. Discussion

It appears relatively easy to describe global energy systems as historically being in a state of reproduction. Like most large technical systems, energy systems are rather resistant to change due to "webs of interdependent relationships…and patterns of culture, norms and ideology" (Geels, 2007). Innovation has been rather incremental and has involved some new technologies, increases in efficiencies, lower costs, or conservation measures. However, the landscape has been dominated by nuclear and fossil fuels. Currently, the landscape has been effected by new scientific evidence concerning climate change and worries of nuclear disaster in a post-Fukushima world that have led to changes in the regime (needs for mitigation). Almost by definition (Geels, 2002), this has involved some period of denial by the regime that a problem actually existed or that there was a need for mitigation. A change is occurring whereby former niche actors and technologies (solar photovoltaics and wind power, in particular) are becoming a greater part of the mainstream technological regime. If current trends continue, a new system can grow out of the old, as major actors within the regime have, for the most part, been the ones to enable the niche technologies. According to definitions supplied by Geels and colleagues (Geels, 2002, 2007; Geels and Kemp, 2007), this change should be denoted as a transformation.

However, this technological transformation is only part of a wider process of change that involves a wider range of social, economic and environmental stakeholders and entities. In addition, new niche innovations could emerge that are not only unrelated to the current regime and landscape, but that could change both dramatically. The door must still be open for other transition pathways as outlined by Geels and Schot (2007). This may be especially true if the current regime became incapable of solving the problem of climate change. For example, the impacts of climate change could be so great at some time in the future so as to go beyond a tipping point and to lead to fuel shortages, some kind of natural disaster (melting ice sheets, changes in ocean currents, etc.) or other cataclysm (increased war, poverty, drought, energy injustice, terrorism, nuclear accident, etc.) which could force a transition to a system that has a completely different trajectory and could be made up of technologies that have yet to be invented. Alternatively, some new technology or energy source could enter the landscape (however improbably from our current perspective) that fundamentally alters the course of life (e.g. cold fusion, new super capacitors, warp drive).

There appears to be only slight evidence to suggest that *transition* and *transformation* authors are writing about fundamentally different concepts. Firstly, no evidence has been found that there is any intentional promotion of different alternatives, and different usages of these terms should not be seen as exercising either tolerance of or resistance to change. Secondly, there appears to be no significant difference in the representation of the complexity of change, the starting or end points of change, or the means by which change occurs. In this regard, the agents and outcomes of change show remarkable similarity throughout article types even though transition articles tend to denote a wider range of social agents. However, there does appear to be differences related to the representation of the speed or continuity of change. While there is general agreement that changes to energy system occur over the long-term, some articles advocate specific changes that may need to occur quickly over the short-term. Moreover, some transformation articles show more focus on the rapid speed of change necessary.

Furthermore, it appears that the concept of change is being framed differently in the transition and transformation article types, and this framing may affect reader understanding of the notion of change to some extent. This difference primarily is seen by the extent to which transition and transformation articles frame the concept as social. Firstly, the problem that motivates the need for change is represented differently. Transition articles tend to highlight a social problem that needs social actors to achieve social goals. Secondly, the underlying actions needed to achieve change are denoted in different ways. While there is high similarity between article types in denoting technologies, energy efficiency, government policies and institutions as agents of change, transition articles additionally highlight human agents to some extent. Thirdly, the obstacles to achieving change are not the same between the article types. Transition articles show a trend of highlighting emotional barriers, and perhaps give the impression that overcoming barriers will be demanding physically and emotionally. In contrast, transformation articles tend to use neutral terms or highlight the manageability of the barriers. Lastly, there are some differences in the way the degree of change necessary is represented in transition and transformation articles. In a few cases, transformation articles denote the nature of change as being radical and some suggest a "fundamental" difference between starting and end points. However, as stated previously, it remains unclear whether this difference in the framing of the concept will affect overall acceptance of or resistance to change. Instead, it appears that the transition articles just go further than the transformation articles in portraying the social aspects of problems, actions and outcomes.

Therefore, it appears that transition articles have more comprehensively described a new direction that pertains to both the socio-technical landscape and the socio-political-technical regime that maintains it. There appears to be little doubt that change to this complex, large socio-technical system is occurring. However, societal drivers seem to be more in the forefront of transition articles. A key element of a transition may be that some aspect of the old system remains relevant enough that the new system retains some aspect of fundamental similarity to the old. This relevance can be quantified by structure, style, aesthetics, or even as how influential the old system was on the new in terms of actors, rules or artefacts. It seems reasonable to assume that societies can experience a transition and remain relevant, but much less reasonable that they can undergo a fundamental transformation (literally a change of form) the same way a purely technical system can. Technologies can easily become irrelevant, societies cannot.

Interestingly, a provocative description of the difference between *transition* and *transformation* is offered from the realm of gender reassignment. One writer (Walsh) makes a concise and strict distinction between the two terms that has some relevance.

> ***While transition represents the physical manifestations that come with a change in gender expression, hormone replacement therapy, and sexual reassignment surgery, transformation is the* process of acknowledging and coming to terms with one's true gender in order to find emotional, spiritual, and relationship wholeness.**

What has been discovered in this study, however, would seem to suggest the exact opposite. Specifically, current scientific journal articles more often denote transformations as the physical manifestations of change while transition articles highlight a higher order of change from a multi-level perspective, one that includes the ways that society motivates, facilitates, and benefits from change. It would follow then that society is the ultimate enabler in a transition, while physical morphologies are more the focus of change in a transformation. It also follows that a transformation can be an integral part of a transition. If the logic is followed that a society can make a transition to a new way of life, then some aspect of society, especially a biological or technical entity, can be transformed as an element of that transition.

This interpretation allows the notions of *transition* and *transformation* to have quantifiably separate meanings while also allowing the notion of transformation to be an element of transition or to be completely independent. It also allows for several other usages of the words from the variety of disciplines discussed in the introduction to be maintained. Moreover, synonymous use of the terms can be permissible as the transformation of some entity can in theory be used as a synecdoche for the transition of some higher order entity. In essence, the part represents the whole. This is similar to how the expression, *I bought some new wheels*, can function as a synecdoche for the expression, *I bought a new car*.

There may also be caution in using the word transformation, and shortening the expression to *energy transformation* as is typically done with *energy transition*. This is because the expression *energy transformation* already has an established meaning that may cause confusion. Energy comes in several forms, such as mechanical, chemical, gravitational, electrical, or thermal. When one form is converted into another it is denoted as an energy transformation in the field of engineering (among others). The gravitational potential energy of water behind a dam is transformed into mechanical energy when the water is allowed to fall through a turbine. In turn, the mechanical energy of the turbine is transformed into electrical energy by means of a generator. Therefore, some care must be taken to ensure that the expressions are not confused in scientific writing.

For these reasons, it would be recommended to limit the use of the term *transformation* to the description of the physical manifestations of change, indeed, to something that actually has a physical form. Alternatively, when describing change from a higher order perspective, one that includes the complexities of societal motivation, facilitation, cost and benefit, the term *transition* would be preferable. Given that large technical systems, such as energy systems, are intricately intertwined with many facets of social life, and that change cannot occur in one sphere without the other, it would therefore be recommended that the term *energy system transition* be used more consistently in the scientific literature as well as in a wider range of media.

5. Conclusion and policy implications

In the end, there currently seems to be an overlapping of the semantic representations and usage of the terms *transition* and *transformation*. In some cases, it also appears that the words are being used interchangeably. In other cases, authors go through great pains to carefully define one term or both. In other cases still, the definition and usage of one author appears to be in complete contradiction with that of another. The consequences of this linguistic confusion may have rather serious consequences in the context of change that is expected to occur in global energy systems in the years to come. First, for authors of scientific manuscripts as well as their editors, this issue can represent an unnecessary (however interesting) burden. Second, confusion on the part of readers may result in a subconscious resistance to the overall message. Misnaming of a concept, especially such an important one, can lead to a diversion of attention away from the importance of the change itself. In the context of creating a more sustainable society and mitigating the very real effects of climate change, such a diversion seems risky. What is most important is that scientific writers and editors have some level of mutual understanding of how these terms can be used and make their choices clear and unambiguous.

Acknowledgements

The authors gratefully acknowledge the public financing of Tekes, the Finnish Funding Agency for Innovation, for the 'Neo-Carbon Energy' project under the number 40101/14.

Appendix A

See Tables A1–A6.

Table A1
Answer to first key question by source and article type. What words are used to define or describe change?

Transition articles		Transition/Transformation articles		Transformation articles	
(Lachman, 2014)	Mandated Managed	(Muench et al., 2014)	Significant Challenge	(Huberty and Zysman, 2010)	Large-scale
(Miller et al., 2015)	Large-scale Significant	(Eom et al., 2015)	Long-term Critical importance Rapid shift	(Jacobsson and Lauber, 2006)	Rapid
(Parag and Janda, 2014)	Systemic	(Butler et al., 2015)	Strong imperatives	(Marcucci and Fragkos, 2015)	Short and long-term
(Zhang et al., 2010)	Long-term	(Bertram et al., 2015)	Long-term Urgency	(Momirlan and Veziroglu, 2005)	Radical Rapid
(Rutter and Keirstead, 2012)	Major	(Pfenninger and Keirstead, 2015)	Choice between renewable, nuclear, or fossil fuels	(Gambhir et al., 2013)	Fundamental
(Hong et al., 2013a)	Ambitious	(Nilsson et al., 2011)	Anticipated Wished-for	(Capros et al., 2014)	Systematic
(Hong et al., 2013b)	Social and economic	(Yuan et al., 2012)	Urgency Magnitude	(van Vuuren et al., 2012)	Fundamental Long-term
		(Späth and Rohracher, 2010)	Guiding vision	(Pregger et al., 2013)	Long-term

Table A2
Answer to second key question by source and article type. How will change proceed?

Transition articles		Transition/Transformation articles		Transformation articles	
(Miller et al., 2015)	Social, economic and political shifts	(Chai and Zhang, 2010)	Options Development Demonstration Binding targets Policy actions	(Jacobsson and Lauber, 2006)	Regulatory framework
(Schubert et al., 2015)	Process	(Eom et al., 2015)	Pathways	(Ydersbond, 2014)	Target Paths
(Peter Andreasen and Sovacool, 2014)	Activity Vision	(Butler et al., 2015)	Processes Realised	(Marcucci and Fragkos, 2015)	Strategies Scenario Targets
(Parag and Janda, 2014)	Process	(Bertram et al., 2015)	Targets	(Bădileanu, 2014)	Performance
(Zhang et al., 2010)	Development	(Pfenninger and Keirstead, 2015)	Options	(Sano et al., 2015)	Pledges Mitigation options
(Morlet and Keirstead, 2013)	Lowest cost technology pathways Evaluations	(Späth and Rohracher, 2010)	Shifts Development Strategizing Discursive strategies	(Gambhir et al., 2013)	Development
(McDowall, 2012)	Optimization Evolution Pathways Development	(Nilsson et al., 2011)	Explored Developments Scenarios Paths Processes	(Pregger et al., 2013)	Targets Scenario Implementation Development Roadmap
(Rutter and Keirstead, 2012)	Strategic Solutions	(Eyre and Baruah, 2015)	Shift Diversified strategy Ambitious goals	(van Vuuren et al., 2012)	Pathways Vision Integrated approach
(Hall and Foxon, 2014)	Evolution	(Yuan et al., 2012)	Pathways Framework	(Capros et al., 2014)	Targets Feasibility
(Hong et al., 2013a)	Aims	(Winskel et al., 2014)	Phases	(Stenzel and Frenzel, 2008)	Development
(Hong et al., 2013b)	Pathway				
(Foxon et al., 2013)	Pathways Branching points Development				
(Hugh et al., 2007)	Roadmap				

Table A3
Answer to third key question by source and article type. What are the barriers to change?

Transition articles		Transition/Transformation articles		Transformation articles	
(Diaz-Rainey and Tzavara, 2012)	Political system Willingness-to-pay Limitations	(Demski et al., 2015)	Wastefulness Conflict	(Jacobsson and Lauber, 2006)	Reluctant government Opposition interests
(Hall and Foxon, 2014)	Cost	(Muench et al., 2014)	Barriers	(Chowdhury et al., 2014)	Institutional barriers
(Schubert et al., 2015)	Political system (possible) Societal limitations Hurdles	(Eom et al., 2015)	Delayed response will result in need for faster transition Challenges Risk	(Bădileanu, 2014)	Negative determinant factors
(Lachman, 2014)	Impediments	(Butler et al., 2015)	Uncertainty	(Delina, 2012)	Challenges
(Peter Andreasen and Sovacool, 2014)	Conflicts	(Pfenninger and Keirstead, 2015)	Cost	(Stenzel and Frenzel, 2008)	Economic effects
(Zhang et al., 2010)	Risks Policy measures	(Winskel et al., 2014)	Erratic public funding Persistent problems	(Pregger et al., 2013)	Associated costs Technological limitation Delaying has significant adverse effects
(Miller et al., 2015)	Policy is too constrained	(Nilsson et al., 2011)	Constraints	(Capros et al., 2014)	Incumbents Resistance proactivity Inertia
(Rutter and Keirstead, 2012)	Constrained by climate change and rising fuel prices	(Eyre and Baruah, 2015)	Challenges Inefficient building stock High penetration of NG Problems Risks Uncertain		
(McDowall, 2012)	Uncertainties Breaking incumbent system 'lock-in' Resistance to change	(Späth and Rohracher, 2010)	Contested processes Conflict Power structures		
(Hong et al., 2013a)	Cost				
(Stenzel and Frenzel,	Stresses				

(continued on next page)

Table A3 *(continued)*

Transition articles		Transition/Transformation articles		Transformation articles	
2008)	Risk				
(Ydersbond, 2014)	Political system Willingness-to-pay Limitations	(Lachman, 2014)	Wastefulness Conflict	(Miller et al., 2015)	Reluctant government Opposition interests
(Delina, 2012)	Cost	(Schubert et al., 2015)	Barriers	(Butler et al., 2015)	Institutional barriers
(Jacobsson and Lauber, 2006)	Political system (possible) Societal limitations Hurdles	(Diaz-Rainey and Tzavara, 2012)	Delayed response will result in need for faster transition Challenges Risk	(Bertram et al., 2015)	Negative determinant factors
(van Vuuren et al., 2012)	Impediments	(Peter Andreasen and Sovacool, 2014)	Uncertainty	(Nilsson et al., 2011)	Challenges
(Marcucci and Fragkos, 2015)	Conflicts	(Zhang et al., 2010)	Cost	(Hong et al., 2013a)	Economic effects
(Bădileanu, 2014)	Risks Policy measures	(Momirlan and Veziroglu, 2005)	Erratic public funding Persistent problems	(Späth and Rohracher, 2010)	Associated costs Technological limitation Delaying has significant adverse effects
(Demski et al., 2015)	Policy is too constrained	(Morlet and Keirstead, 2013)	Constraints	(Eyre and Baruah, 2015)	Incumbents Resistance proactivity Inertia
(Capros et al., 2014)	Constrained by climate change and rising fuel prices	(Hall and Foxon, 2014)	Challenges Inefficient building stock High penetration of NG Problems Risks Uncertain		
(Yuan et al., 2012)	Uncertainties Breaking incumbent system 'lock-in' Resistance to change	(McDowall, 2012)	Contested processes Conflict Power structures		
(Stenzel and Frenzel, 2008)	Cost				
(Hong et al., 2013b)	Stresses Risk				

Table A4
Answer to fourth key question by source and article type. What or who are the agents and facilitators of change?

Transition articles		Transition/Transformation articles		Transformation articles	
(Lachman, 2014)	Effort Stakeholders Policy	(Demski et al., 2015)	Public acceptance Public values Attitudes Efficiency Dialogue Robust decision-making Anticipating conflict	(Huberty and Zysman, 2010)	Technologies Research policy Transformation of economy Increase efficiency
(Miller et al., 2015)	Recommendations Rethinking Policy Governance	(Chai and Zhang, 2010)	Technology Policy Intensive efforts Promote research Economic incentives Public R & D support Further actions Radically innovative technologies International collaborations	(Jacobsson and Lauber, 2006)	New technologies Spread of technologies Advocacy Support policies Modest price
(Schubert et al., 2015)	Technology Social acceptance	(Muench et al., 2014)	Increase RE Technologies Policy Alignment of interests of market participants Regulations Information	(Ydersbond, 2014)	RE production Political and public policies RE technologies Cost-competitiveness World leaders
(Diaz-Rainey and Tzavara, 2012)	Investment	(Eom et al., 2015)	Optimal policies Ambitious mitigation strategies Low GHG emitting technology Deployment measures Facilitation	(Marcucci and Fragkos, 2015)	Drivers Natural resources Backstop technologies Policies

(continued on next page)

Table A4 *(continued)*

Transition articles		Transition/Transformation articles		Transformation articles	
			CCS		
(Peter Andreasen and Sovacool, 2014)	Critical stakeholders Influential actors Technical development Hydrogen technology advancement Use of renewable resources	(Butler et al., 2015)	Public attitudes Acceptability Efforts Enact Policy	(Chowdhury et al., 2014)	Developing technologies Creating an initial market Policy Incentives Diffusion of PV technology Wider use of RE technology
(Parag and Janda, 2014)	Actors Strategies	(Winskel et al., 2014)	Strong policy imperatives Leading role of private business Energy innovation	(Bădileanu, 2014)	Positive determinant factors Electricity market Price
(Zhang et al., 2010)	Risk management	(Pfenninger and Keirstead, 2015)	Technological options Emission restrictions	(Sano et al., 2015)	Short-term emission fixes Technologies Fuel switching
(Momirlan and Veziroglu, 2005)	Hydrogen utilization	(Bertram et al., 2015)	Limit on emissions Policy signals Retire coal capacity Low-carbon technologies Energy efficiency Facilitation	(Gambhir et al., 2013)	Technology-specific solutions Measures Options Mix of technologies Increased electrification Energy efficiency
(Morlet and Keirstead, 2013)	Policy Governance	(Nilsson et al., 2011)	Tool Technical, economic and policy change Political and institutional factors	(Delina, 2012)	Improvement of technology Development of new technologies Coherent governance Institutional design Promote Policy Enabling conditions
(Hall and Foxon, 2014)	Investment Enabler Stakeholders Partners and investors	(Eyre and Baruah, 2015)	Systematic change in space heating systems Minimal policy intervention Heat pumps Energy efficiency Biomass	(Capros et al., 2014)	EU Roadmap 2050 Policy Accelerated energy efficiency Transport electrification Supply-side restructuring High RES CCS, Nuclear power
(Rutter and Keirstead, 2012)	Wider changes in technology and society Increased efficiency Driven by urbanisation and access to basic energy services	(Yuan et al., 2012)	Manage Technology options Policy Policy-makers Stakeholders	(van Vuuren et al., 2012)	Motivated by challenges and critical issues Energy efficiency Scale up of investments RD & D
(McDowall, 2012)	Alternate fuel Hydrogen Decision points Policy responses	(Späth and Rohrracher, 2010)	Mobilizing social actors Co-ordination of dispersed agency Promotion Actor network Systematically exploiting resources Anticipation of conflict Modify durable power structures Orient strategic action	(Pregger et al., 2013)	Political consensus Policy targets Energy efficiency RE Policy measures Investments Strong market dynamics New generation technologies
(Hong et al., 2013a)	Plan Target Technologies Technical performance Efficiency Promoted Implemented Facilitation			(Stenzel and Frenzel, 2008)	Support Technological capabilities Political activities Shaping of regulatory environment Coordination of strategies Novel policy shaping
(Hong et al., 2013b)	Improving energy efficiency Utilizing renewable resources Policy				
(Foxon et al., 2013)	Triggers Governance Actors Risk mitigation strategies				
(Hugh et al., 2007)	Planning Facilitating Actors				

Table A5
Answer to fifth key question by source and article type. What is the outcome of change?

Transition articles		Transition/Transformation articles		Transformation articles	
(Lachman, 2014)	Sustainable energy system	(Chai and Zhang, 2010)	Sustainable energy system for China	(Huberty and Zysman, 2010)	Mitigate climate change
(Schubert et al., 2015)	Normative targets Goals Replace fossil fuels Reduce emissions Reduce import dependencies Phase out nuclear energy	(Demski et al., 2015)	Desirable futures Security Stability Social justice Fairness Autonomy and power Low carbon energy	(Jacobsson and Lauber, 2006)	Achievement Arrest climate change Low-carbon economy
(Diaz-Rainey and Tzavara, 2012)	Decarbonized energy system	(Pfenninger and Keirstead, 2015)	Energy security	(Ydersbond, 2014)	95% reduction of GHGs
(Peter Andreasen and Sovacool, 2014)	Hydrogen economy Mitigation of CO_2	(Eom et al., 2015)	Goal Limiting climate forcing to 450 ppm	(Marcucci and Fragkos, 2015)	Global GHG target of 450 ppm
(Parag and Janda, 2014)	Low carbon society	(Butler et al., 2015)	Low carbon energy sytem for UK	(Chowdhury et al., 2014)	Meet environmental and climate challenge
(Zhang et al., 2010)	Targets Sustainable energy supply	(Bertram et al., 2015)	$< 2°$ increase Achieving stringent long-term climate targets	(Bădileanu, 2014)	Maintain current system of electricity supply
(Momirlan and Veziroglu, 2005)	Benefits Opportunities Cleaner planet Sustainable energy system	(Muench et al., 2014)	Solution Diversity of solutions Increase share of RE in national energy mixes	(Sano et al., 2015)	Global GHG reduction
(Morlet and Keirstead, 2013)	Carbon target Emission reductions Combat climate change	(Winskel et al., 2014)	Decarbonization of UK	(Gambhir et al., 2013)	Carbon abatement
(Hall and Foxon, 2014)	Benefit Energy security Decarbonization Public goods Economic opportunities	(Nilsson et al., 2011)	Low carbon Swedish energy system	(Delina, 2012)	Energy efficiency
(Rutter and Keirstead, 2012)	Access to basic services Mitigate climate change Save on fuel prices	(Eyre and Baruah, 2015)	Climate change mitigation Low carbon heating	(Capros et al., 2014)	EU decarbonization 80% GHG reduction
(McDowall, 2012)	Decarbonization Hydrogen transition	(Yuan et al., 2012)	Low carbon power sector of China	(van Vuuren et al., 2012)	Sustainability of global energy system
(Hong et al., 2013a)	Enhance energy security Mitigate emissions Develop RE industry	(Späth and Rohracher, 2010)	Save region from economic decay Greater sustainability	(Pregger et al., 2013)	Economic benefits Fuel cost savings Lower fuel imports
(Hong et al., 2013a)	Meet energy demand Mitigate emissions Utilize renewable resources			(Stenzel and Frenzel, 2008)	Diffusion of RE technologies
(Foxon et al., 2013)	UK low carbon electricity future by 2050				
(Hugh et al., 2007)	Hydrogen energy system				
(van Vuuren et al., 2012)	Sustainable energy system	(Oxford University Press)	Sustainable energy system for China	(Chappin and Ligtvoet, 2014)	Mitigate climate change
(Jacobsson and Lauber, 2006)	Normative targets Goals Replace fossil fuels Reduce emissions Reduce import dependencies Phase out nuclear energy	(Lachman, 2014)	Desirable futures Security Stability Social justice Fairness Autonomy and power Low carbon energy	(Miller et al., 2015)	Achievement Arrest climate change Low-carbon economy
(Ydersbond, 2014)	Decarbonized energy system	(Zhang et al., 2010)	Energy security	(Muench et al., 2014)	95% reduction of GHGs
(Marcucci and Fragkos, 2015)	Hydrogen economy Mitigation of CO_2	(Diaz-Rainey and Tzavara, 2012)	Goal Limiting climate forcing to 450 ppm	(Eom et al., 2015)	Global GHG target of 450 ppm
(Chowdhury et al., 2014)	Low carbon society	(Peter Andreasen and Sovacool, 2014)	Low carbon energy sytem for UK	(Butler et al., 2015)	Meet environmental and climate challenge
(Bădileanu, 2014)	Targets Sustainable energy supply	(Parag and Janda, 2014)	$< 2°$ increase Achieving stringent long-term climate targets	(Bertram et al., 2015)	Maintain current system of electricity supply
(Sano et al., 2015)	Benefits Opportunities Cleaner planet Sustainable energy system	(Schubert et al., 2015)	Solution Diversity of solutions Increase share of RE in national energy mixes	(Pfenninger and Keirstead, 2015)	Global GHG reduction
(Gambhir et al., 2013)	Carbon target Emission reductions Combat climate change	(Momirlan and Veziroglu, 2005)	Decarbonization of UK	(Winskel et al., 2014)	Carbon abatement
(Delina, 2012)	Benefit Energy security Decarbonization Public goods	(Morlet and Keirstead, 2013)	Low carbon Swedish energy system	(Nilsson et al., 2011)	Energy efficiency

(continued on next page)

Table A5 *(continued)*

Transition articles		Transition/Transformation articles		Transformation articles	
	Economic opportunities				
(Capros et al., 2014)	Access to basic services Mitigate climate change Save on fuel prices	(Hall and Foxon, 2014)	Climate change mitigation Low carbon heating	(Eyre and Baruah, 2015)	EU decarbonization 80% GHG reduction
(Yuan et al., 2012)	Decarbonization Hydrogen transition	(Rutter and Keirstead, 2012)	Low carbon power sector of China	(Huberty and Zysman, 2010)	Sustainability of global energy system
(Pregger et al., 2013)	Enhance energy security Mitigate emissions Develop RE industry	(McDowall, 2012)	Save region from economic decay Greater sustainability	(Späth and Rohracher, 2010)	Economic benefits Fuel cost savings Lower fuel imports
(Stenzel and Frenzel, 2008)	Meet energy demand Mitigate emissions Utilize renewable resources			(Hong et al., 2013a)	Diffusion of RE technologies
(Hong et al., 2013b)	UK low carbon electricity future by 2050				
(Foxon et al., 2013)	Hydrogen energy system				

Table A6
Key words by source and article type.

Transition articles		Transition/Transformation articles		Transformation articles	
(Lachman, 2014)	Energy system transition management Socio-technical systems Panama	(Demski et al., 2015)	Public acceptability Public perception Energy system transitions	(Jacobsson and Lauber, 2006)	Renewable energy Regulatory framework Market creation
(Miller et al., 2015)	Socio-energy system Governance Society Transition Design	(Chai and Zhang, 2010)	Energy technology Energy policy Sustainable development China	(Ydersbond, 2014)	Renewable energy Energy policy Transformation Comparative study Historical institutionalism Sweden, Norway
(Schubert et al., 2015)	Energy scenarios Social acceptance Political feasibility Institutions	(Muench et al., 2014)	Energy distribution Power system Barriers	(Marcucci and Fragkos, 2015)	Regional decomposition analysis Model inter-comparison Climate change mitigation pathways Backstop technologies
(Diaz-Rainey and Tzavara, 2012)	Innovation diffusion Willingness-to-pay Energy system transition Financing renewables Green consumerism Smart grids	(Eom et al., 2015)	Near-term climate policy Technology deployment Emission pathway Technology upscaling	(Chowdhury et al., 2014)	PV diffusion Energy policy Feed-in tariff Japan Germany
(Peter Andreasen and Sovacool, 2014)	Hydrogen fuel cells Critical stakeholder analysis Hydrogen policy	(Butler et al., 2015)	Public acceptability Uncertainty Energy policy Energy transitions	(Bădileanu, 2014)	Energy system Price liberalization Electricity market Energy welfare
(Parag and Janda, 2014)	Energy system transition Middle-out Agency and capacity Middle actors	(Bertram et al., 2015)	Climate change mitigation Energy systems modelling Energy efficiency Carbon dioxide emissions AMPERE Integrated assessment	(Sano et al., 2015)	Climate change mitigation Decomposition analysis Energy end-use sector Global energy system model
(Zhang et al., 2010)	Renewable energy Energy supply Market development Public policy China	(Pfenninger and Keirstead, 2015)	Energy system modelling Energy policy Renewable energy	(Gambhir et al., 2013)	China CO_2 emissions Low-carbon technology
(Momirlan and Veziroglu, 2005)	Hydrogen Environment Chemical properties Fuel CO_2 emissions Atomic hydrogen/carbon ratio Pollutants	(Winskel et al., 2014)	Energy Technology Innovation	(Delina, 2012)	Energy efficiency Governance Motivation Capacity Intervention Institutions
(Morlet and Keirstead, 2013)	Urban energy systems Governance Scenario analysis	(Nilsson et al., 2011)	Backcasting Systems Institutions Sweden Climate	(Capros et al., 2014)	EU decarbonization pathways Climate policy delays Energy roadmap EU energy policy Technological limitations

(continued on next page)

Table A6 *(continued)*

Transition articles		Transition/Transformation articles		Transformation articles	
(Hall and Foxon, 2014)	Smart grids Political economy Co-evolution	(Eyre and Baruah, 2015)	Governance Scenarios Heating Fuel switching Electrification Energy efficiency Heat pumps	(Pregger et al., 2013)	Energy scenario Renewable energy Economic effect
(Rutter and Keirstead, 2012)	Urban energy systems History Transitions	(Yuan et al., 2012)	Multi-level perspective Energy transition management China Power systems	(Stenzel and Frenzel, 2008)	Innovation diffusion Energy system transformation Corporate political activities
(McDowall, 2012)	Scenarios Energy system models Technological transition Hydrogen economy	(Späth and Rohracher, 2010)	Guiding visions Transition management Multi-level framework Regional governance Energy systems	(Stenzel and Frenzel, 2008)	Innovation diffusion Energy system transformation Corporate political activities
(Hong et al., 2013a)	China Renewable 12th five year plan				
(Hong et al., 2013b)	Renewable Jiangsu 2050				
(Foxon et al., 2013)	Branching points Transition pathway Path dependency				
(Hugh et al., 2007)	Hydrogen energy system Transitions Roadmap Actors Qualitative analysis				

References

Bădileanu, M., 2014. Crossroads in the past 23 years history of the Romanian energy system. Procedia Econ. Financ. 8 (14), 60–65.

Bertram, C., Johnson, N., Luderer, G., Riahi, K., Isaac, M., Eom, J., 2015. Carbon lock-in through capital stock inertia associated with weak near-term climate policies. Technol. Forecast. Soc. Change 90 (PA), 62–72.

Boulding, K.E., 1964. The Meaning of the 20th Century: The Great Transition. Harper Colophon Books, New York.

Butler, C., Demski, C., Parkhill, K., Pidgeon, N., Spence, A., 2015. Public values for energy futures: framing, indeterminacy and policy making. Energy Policy 87, 665–672.

Cambridge University Press. Cambridge Dictionaries Online. [Online]. Available: 〈http://dictionary.cambridge.org/〉. (accessed 24 June 2015).

Capros, P., Paroussos, L., Fragkos, P., Tsani, S., Boitier, B., Wagner, F., Busch, S., Resch, G., Blesl, M., Bollen, J., 2014. European decarbonisation pathways under alternative technological and policy choices: a multi-model analysis. Energy Strateg. Rev. 2 (3–4), 231–245.

Chai, Q., Zhang, X., 2010. Technologies and policies for the transition to a sustainable energy system in China. Energy 35 (10), 3995–4002.

Chappin, E.J.L., Ligtvoet, A., 2014. Transition and transformation: a bibliometric analysis of two scientific networks researching socio-technical change. Renew. Sustain. Energy Rev. 30, 715–723.

Chowdhury, S., Sumita, U., Islam, A., Bedja, I., 2014. Importance of policy for energy system transformation: diffusion of PV technology in Japan and Germany. Energy Policy 68, 285–293.

Daily, G.C., Walker, B.H., 2000. Seeking the great transition. Nature 403 (6767), 243–245.

Dator, J., 2009. Alternative futures at the Manoa school. J. Futur. Stud. 14 (2), 1–18.

Delina, L.L., 2012. Coherence in energy efficiency governance. Energy Sustain. Dev. 16 (4), 493–499.

Demski, C., Butler, C., Parkhill, K.A., Spence, A., Pidgeon, N.F., 2015. Public values for energy system change. Glob. Environ. Chang. 34, 59–69.

Diaz-Rainey, I., Tzavara, D., 2012. Financing the decarbonized energy system through green electricity tariffs: a diffusion model of an induced consumer environmental market. Technol. Forecast. Soc. Change 79 (9), 1693–1704.

Eldredge, N., Gould, S.J., 1972. Punctuated equilibria: an alternative to phyletic gradualism. Models Paleobiol., 1–35.

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 (PA), 73–88.

Eyre, N., Baruah, P., 2015. Uncertainties in future energy demand in UK residential heating. Energy Policy 87, 641–653.

Fairclough, N., Wodak, R., 1997. Critical discourse analysis. In: Discourse studies: A multidisciplinary introduction, vol. 2, pp. 258–281.

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.

Gambhir, A., Schulz, N., Napp, T., Tong, D., Munuera, L., Faist, M., Riahi, K., 2013. A hybrid modelling approach to develop scenarios for China's carbon dioxide emissions to 2050. Energy Policy 59, 614–632.

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., 2007. Transformations of large technical systems: a multi-level analysis of the Dutch highway system (1950–2000). Sci. Technol. Hum. 32 (2), 123–149.

Geels, F.W., 2012. A socio-technical analysis of low-carbon transitions: introducing the multi- level perspective into transport studies. J. Transp. Geogr. 24, 471–482.

Geels, F.W., Kemp, R., 2007. Dynamics in socio-technical systems: typology of change processes and contrasting case studies. Technol. Soc. 29 (4), 441–455.

Geels, F.W., Schot, J., 2007. Typology of sociotechnical transition pathways. Res. Policy 36 (3), 399–417.

Gould, S.J., 1977. The return of hopeful monsters. Nat. Hist. 86, 22–30.

Hall, S., Foxon, T.J., 2014. Values in the smart grid: the co-evolving political economy of Smart distribution. Energy Policy 74 (C), 600–609.

Hockenos, P., 2012. The Energiewende, ZEIT Online. Nov. 15. [Online]. Available: 〈http://pdf.zeit.de/2012/47/Energiewende-Deutsche-Begriffe-Englisch.pdf〉. (accessed 17 July 2015).

Hong, L., Zhou, N., Fridley, D., Raczkowski, C., 2013a. Assessment of China's renewable energy contribution during the 12th Five Year Plan. Energy Policy 62 (2013), 1533–1543.

Hong, L., Lund, H., Mathiesen, B.V., Möller, B., 2013b. 2050 Pathway to an active renewable energy scenario for Jiangsu province. Energy Policy 53, 267–278.

Huberty, M., Zysman, J., 2010. An energy system transformation: framing research choices for the climate challenge. Res. Policy 39 (8), 1027–1029.

Hugh, M.J., Yetano Roche, M., Bennett, S.J., 2007. A structured and qualitative systems approach to analysing hydrogen transitions: key changes and actor mapping. Int. J. Hydrog. Energy 32 (10–11), 1314–1323.

Jacobsson, S., Lauber, V., 2006. The politics and policy of energy system transformation – explaining the German diffusion of renewable energy technology. Energy Policy 34 (3), 256–276.

Jorgenson, D.W., 1986. The great transition: energy and economic change. Energy J., 1–13.

Krause, F., Bossel, H., Müller-Reißmann, K., 1980. In: Freiburg, S. (Ed.), Energie-Wende: Wachstum und Wohlstand ohne Erdöl und Uran; ein Alternativ-Bericht des Öko-Instituts. Fischer.Öko-Institut, Frankfurt.

Lachman, D.A., 2014. A combination of existing concepts and approaches to take on energy system transitions – The Republic of Panama as a case-study. Sustain. Energy Technol. Assess. 5, 84–94.

Lieberthal, K., Lieberthal, G., 2003. The great transition. Harv. Bus. Rev. 81, 70–81.

Lovins, A.B., 1977. Soft energy paths: toward a durable peace. Environ. Toxicol. Chem.

32 (1), 207–221.
Marcucci, A., Fragkos, P., 2015. Drivers of regional decarbonization through 2100: a multi-model decomposition analysis. Energy Econ. 51, 111–124.
McDowall, W., 2012. Possible hydrogen transitions in the UK: critical uncertainties and possible decision points. Energy Procedia 29 (0), 409–420.
Merriam-Webster. Merriam-Webster Dictionary. [Online]. Available: ⟨http://www.merriam-webster.com/⟩. (accessed 24 June 2015).
Miller, C.A., Richter, J., O'Leary, J., 2015. Socio-energy systems design: a policy framework for energy transitions. Energy Res. Soc. Sci. 6, 29–40.
Momirlan, M., Veziroglu, T.N., 2005. The properties of hydrogen as fuel tomorrow in sustainable energy system for a cleaner planet. Int. J. Hydrog. Energy 30 (7), 795–802.
Morlet, C., Keirstead, J., 2013. A comparative analysis of urban energy governance in four European cities. Energy Policy 61, 852–863.
Muench, S., Thuss, S., Guenther, E., 2014. What hampers energy system transformations? The case of smart grids. Energy Policy 73, 80–92.
Nilsson, M., Nilsson, L.J., Hildingsson, R., Stripple, J., Eikeland, P.O., 2011. The missing link: bringing institutions and politics into energy future studies. Futures 43 (10), 1117–1128.
Oxford University Press. English Dictionary. [Online]. Available: ⟨http://www.oxforddictionaries.com/⟩. (accessed 01 January 2015).
Parag, Y., Janda, K.B., 2014. More than filler: middle actors and socio-technical change in the energy system from the 'Middle-out. Energy Res. Soc. Sci. 3 (C), 102–112.
Peter Andreasen, K., Sovacool, B.K., 2014. Energy sustainability, stakeholder conflicts, and the future of hydrogen in Denmark. Renew. Sustain. Energy Rev. 39, 891–897.
Pfenninger, S., Keirstead, J., 2015. Renewables, nuclear, or fossil fuels? Scenarios for Great Britain's power system considering costs, emissions and energy security. Appl. Energy 152, 83–93.
Polanyi, K., 1944. The great transformation. Polit. Sci. Q. 59 (4), 630.
Pregger, T., Nitsch, J., Naegler, T., 2013. Long-term scenarios and strategies for the deployment of renewable energies in Germany. Energy Policy 59, 350–360.
Raskin, P., Banuri, T., Gallopin, G., Gutman, P., Hammond, A., Kates, R., Swart, R., 2002. Great Transition. Umbrüche und Übergänge auf dem Weg zu einer planetarischen Gesellschaft, Mater. Soz. Ökologie, vol. 20.
Roggema, R., Vermeend, T., van den Dobbelsteen, A., 2012. Incremental change, transition or transformation? Optimising change pathways for climate adaptation in spatial planning. Sustainability 4 (10), 2525–2549.
Rutter, P., Keirstead, J., 2012. A brief history and the possible future of urban energy systems. Energy Policy 50, 72–80.
Sano, F., Wada, K., Akimoto, K., Oda, J., 2015. Assessments of GHG emission reduction scenarios of different levels and different short-term pledges through macro- and sectoral decomposition analyses. Technol. Forecast. Soc. Change 90 (PA), 153–165.
Schmid, E., Pechan, A., Mehnert, M., Eisenack, K., 2017. Imagine all these futures: on heterogeneous preferences and mental models in the German energy transition. Energy Res. Soc. Sci. 27, 45–56.
Schubert, D.K.J., Thuß, S., Möst, D., 2015. Does political and social feasibility matter in energy scenarios? Energy Res. Soc. Sci. 7, 43–54.
Späth, P., Rohracher, H., 2010. 'Energy regions': the transformative power of regional discourses on socio-technical futures. Res. Policy 39 (4), 449–458.
Stark, D., Bruszt, L., 1998. Postsocialist Pathways: Transforming Politics and Property in East Central Europe. Cambiridge University Press, Cambridge.
Stenzel, T., Frenzel, A., 2008. Regulating technological change – the strategic reactions of utility companies towards subsidy policies in the German, Spanish and UK electricity markets. Energy Policy 36 (7), 2645–2657.
van Vuuren, D.P., Nakicenovic, N., Riahi, K., Brew-Hammond, A., Kammen, D., Modi, V., Nilsson, M., Smith, K.R., 2012. An energy vision: the transformation towards sustainability-interconnected challenges and solutions. Curr. Opin. Environ. Sustain. 4 (1), 18–34.
Verbong, G.P.J., Geels, F.W., 2010. Exploring sustainability transitions in the electricity sector with socio-technical pathways. Technol. Forecast. Soc. Change 77 (8), 1214–1221.
Walsh, B., Transition vs. Transformation. [Online]. Available: ⟨http://gendernexus.org/2011/08/transition-vs-transformation/⟩. (accessed 02 August 2015).
Wiktionary. Wiktionary, the free dictionary. [Online]. Available: ⟨https://www.wiktionary.org/⟩. (accessed 24 June 2015).
Winskel, M., Radcliffe, J., Skea, J., Wang, X., 2014. Remaking the UK's energy technology innovation system: from the margins to the mainstream. Energy Policy 68, 591–602.
Ydersbond, I.M., 2014. Aiming to be environmental leaders, but struggling to go forward: Sweden and Norway on energy system transformation. Energy Procedia 58, 16–23.
Yuan, J., Xu, Y., Hu, Z., Yu, Z., Liu, J., Hu, Z., Xu, M., 2012. Managing electric power system transition in China. Renew. Sustain. Energy Rev. 16 (8), 5660–5677.
Zhang, X., Ruoshui, W., Molin, H., Martinot, E., 2010. A study of the role played by renewable energies in China's sustainable energy supply. Energy 35 (11), 4392–4399.