Technological Forecasting & Social Change xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

Review

Experimenting for sustainability transitions: A systematic literature review

Frans Sengers [b,*], Anna J. Wieczorek [a], Rob Raven [b]

[a] Eindhoven University of Technology, Netherlands
[b] Utrecht University, Netherlands

ARTICLE INFO

Article history:
Received 17 March 2015
Received in revised form 25 May 2016
Accepted 31 August 2016
Available online xxxx

Keywords:
Experiments
Sustainability transitions
Systematic literature review

ABSTRACT

This review paper systematically queries the Sustainability Transitions literature to unpack the concept of 'experimentation'. We define an experiment as an inclusive, practice-based and challenge-led initiative, which is designed to promote system innovation through social learning under conditions of uncertainty and ambiguity. A distinction is made between various terms (niche experiments, bounded socio-technical experiments, transition experiments, sustainability experiments and grassroots experiments), each with their own theoretical backgrounds and discursive and empirical focal points. Observed patterns and trends in the literature are discussed, as well as promising lines of enquiry for further exploration of- and a reflection on experimenting for sustainability transitions in the context of the welfare state.

Contents

1. Introduction

The notion of 'experimentation' occupies a central position within the academic field that investigates transformations towards sustainable socio-technical systems. It is the focus on experimentation as a key agent of change that sets this Sustainability Transitions field apart from the wider literature of social change and policy theory (Markard et al., 2012; Meadowcroft, 2011; Van den Bergh, 2012). This idea of 'socio-technical experimentation' can be contrasted with the notion of experimentation used in the natural sciences. Natural science experiments can broadly be interpreted as a practice that take place in the confines of a laboratory or an otherwise strictly controlled environment as a way to find hard objective truths about material reality. Socio-technical experimentation, on the other hand, implies a more engaged

* Corresponding author.
E-mail addresses: f.sengers@uu.nl (F. Sengers), a.j.wieczorek@tue.nl (A.J. Wieczorek), r.p.j.m.raven@tue.nl (R. Raven).

http://dx.doi.org/10.1016/j.techfore.2016.08.031
0040-1625/

and social constructivist position: society is itself a laboratory and a variety of real-world actors commit to the messy experimental processes tied up with the introduction of alternative technologies and practices in order to purposively re-shape social and material realities. In the context of transitions, socio-technical experiments are seen as important seeds of change that may eventually lead to a profound shift in the way a human need or societal function – such as the provision of energy or mobility – is being met. As precious yet-to-germinate microcosms of sustainable systems and practices, the alternative socio-technical configurations embodied in experiments emerge in real-life contexts with the aim of technological, social and institutional learning. The promise is that learning and demonstration effects of experiments add to the momentum of emerging sustainable configurations, which are geared to transform unsustainable socio-technical systems.

While it is clear that experimentation is one of the central concepts in the Sustainability Transitions literature, it is unclear what transition scholars exactly mean when they evoke this term. Given that the literature on experimentation in the field of Sustainability Transitions is growing rapidly and quickly giving rise to a diversity of additional perspectives,[1] we feel that there is now more than ever a need to provide a clear and up-to-date overview of the research that has been conducted in our field under the banner of the experiment. As such, the goal of this paper is to interrogate the salient terms in the academic transition studies debate on experimenting for sustainability as well as the conceptual relationship between these terms. Because the use of concept of the experiment in the Sustainability Transitions literature is on the one hand highly central, but on the other hand also highly wide-ranging, we believe that reviewing this literature warrants a thorough and systematic approach. Following the guidelines of a 'systematic literature review' (Petticrew and Roberts, 2006) our efforts are conducted with a defined research question in mind: *How have scholars in the field of Sustainability Transitions conceived of and addressed the concept of the experiment?* In addressing this question, our main aim is to provide a clear overview of various lines of thought and to come up with a useful definition of an experiment in the context of this field of research. Additionally, we also aim to point out promising avenues for further exploration and – in line with the main topic of this special issue – to reflect on experimentation in the context of sustainability transitions in welfare states.

The paper is structured as follows. Section 2 describes the methodological approach. Section 3 traces the roots of thinking about experimentation through time and highlights where different conceptual variations of this notion come in and branch off, as well as what the various conceptualizations suggest about the specific role of experiments. Section 4 provides discussion and reflection as well as a useful defintion of experimentation. Section 5 briefly concludes and sketches out an agenda for future research.

2. Methods

Within the social sciences, systematic reviewing has been developed as a specific method for identifying and synthesizing research findings (Petticrew and Roberts, 2006). The systematic review is considered particularly useful to disseminate the key findings of large and complex bodies of research literature and it employs a transparent and rigorous (more or less protocol-driven) approach to identify and synthesize all the available research findings of sufficient quality concerning a specific research question or subject (Higgins and Green, 2008). Instead of just rigidly applying an inflexible and restricted procedure, systematic reviews should be guided by a set of clear principles in order to highlight opportunities for further research (Briner and Denyer, 2010). Victor (2008: 1) argues that the systematic literature review can be distinguished from a traditional literature review by a particular emphasis upon the following features: "(1) as far as possible, it should be comprehensive in its coverage of the literature; (2) pay careful attention to the quality of included evidence; (3) take a clear, systematic approach to the synthesis of the data; and (4) generally follow transparent and rigorous processes".

Taking these four features to heart, we selected a comprehensive set of contributions that adequately represent the body of work published within the field of Sustainability Transitions (we limit ourselves to how the role of experiments is conceptualized by this community of scholars[2]). Regarding the 'quality of the evidence' we have to extend the idea of a systematic review beyond the positivist methodological realm of evidence-based medicine from where it emerged and fit it to a more constructivist approach to scientific knowledge that underlies much of the work about sustainability transitions. But we agree that the findings upon which we build our analysis should be of high-quality (with a preference for highly cited books and peer reviewed journal articles). For the sake of rigor and transparency, the process of identifying the set of publications, which serves as the basis for this review, is discussed below.

Notwithstanding that there is no clear single way to define which contributions are 'in' and which are 'out' of the rapidly growing field of Sustainability Transitions, there have been at least three earlier efforts to map these contours and to identify the set of publications that constitute this field. This includes the most recent list of transition publications[3] compiled by the chairman of the Sustainability Transitions Research Network (Geels, 2013a, 2013b) and two bibliometric analyses using a specific search query in the Scopus database (Chappin and Ligtvoet, 2014; Markard et al., 2012). As the starting point for our analysis we have chosen to include all the publications from the inception of the field in the 1990s up to and including the year 2015 that can be identified in these three ways and selected only the contributions (peer reviewed articles, books and book chapters) that mention the term 'experiment*' (that is the word 'experiment' and variations, such as 'experiments', 'experimental' or 'experimentation') in their title, key-words or abstracts.[4] This yielded 150 publications. Using our own assessment – based on our combined expertise and knowledge of the transitions field – we identified 20 additional prominent Sustainability Transitions publications about experimentation, which were not found by the protocol-driven search of the STRN list and Scopus database,

[1] Especially at a time when important new conceptual contributions on experimentation are stacking up (e.g. Bulkeley et al., 2015), when the rapidly growing scholarly community of Sustainability Transitions is moving out of its initial innovation studies niche to have an impact on wider sustainability research (Geels, 2013a, b), and when more researchers from other fields of enquiry (e.g. geography, urban studies) and other parts of the world (e.g. non-OECD countries) are moving in.

[2] This is a deliberate choice. Over the last decade this field of study has given rise to a fairly cohesive and integrated community of scholars, who meet each other at workshops and conferences, and read and cite each other's work (Geels, 2013a, b; Chappin and Ligtvoet, 2014). As members of the Sustainability Transitions community we are in a good position to write *about* developments within our field. We hope, however, that the contribution of this paper is *not limited to* this field. Our aim is indeed to present a comprehensive up-to-date overview to insiders as well as scholars from other research communities by showing how a relatively coherent body of work has made sense of experimentation.

[3] See Geels 2013a. The current 2013 version of this list contains 643 publications (mainly journal articles, but also books, book chapters and viewpoints).

[4] Chappin and Ligtvoet (2014) sketched out the contours of the transition studies field by identifying a set of publications based on the terms 'transition' and 'transformation' within the Scopus Database (http://www.scopus.com/). The search query we used is based on the same idea, but modified in order to find the articles in the sustainability transitions field which are specifically about experimentation. The following Boolean search query was used: *TITLE-ABS-KEY(experiment* AND (transition OR transformation) AND (socio-technical OR socio-technical OR societal OR technological OR sustainability))*. We first used this search query to find articles about experimentation within a set of the twenty most highly cited core articles in the sustainability transitions field (see Markard et al., 2012 for this list). We then expanded the set of articles in which we searched with this query: first the set of publications which cite at least one of those twenty core articles and all of the publications in Scopus (though for the latter case we hand-picked the articles which we deemed to be part of the sustainability transitions field — this last step was undertaken because the record in Scopus on which publication cites which other publication is incomplete). We did not include publications forthcoming after 2015.

Please cite this article as: Sengers, F., et al., Experimenting for sustainability transitions: A systematic literature review, Technol. Forecast. Soc. Change (2016), http://dx.doi.org/10.1016/j.techfore.2016.08.031

but which should be included in our view.[5] For this total of 170 key publications we have identified crucial characteristics of the ways in which experimentation is conceptualized.[6]

As an additional exercise to help identify recent developments and current trends in debates about experimentation we have also screened all accepted abstracts that were submitted to the annual International Sustainability Transitions (IST) conferences.[7] In order to trace the ontological foundations of each conceptualization of experiments we have analyzed the most cited 'core' literature from both within as well as outside of the field of Sustainability Transitions.[8] Besides studying the literature and its terminology with regard to experimentation, we have looked at the descriptions of the actual experiments in order to find out which domains or 'societal functions' were studied (e.g. transport, energy, water) and where (e.g. an island in the Netherlands, cities in India, a neighborhood in Boston). Tracing these elements through time allows us to identify a number of patterns and trends in the kinds of experimental activities and settings that have been studied over the years.

Since literature contributions are embedded in their field through citation (Garfield, 1972), we have also conducted a citation analysis for these publications. This has been done to get an indication as to which the key contributions are (i.e. the most highly cited ones) and show how these relate to one another with time as an additional variable (i.e. clusters of high internal citation 'branch off' from mainstreamed lines of reasoning over time).

3. Experiments in the sustainability transitions literature

Through the 170 identified publications, starting from the emergence of the field in the 1990s all the way up to recent developments in 2015, we can trace at least five unique terms that have been coined and widely mobilized. These terms have been taken up by consecutive cohorts of transition scholars in order to identify specific types of experiments and to describe the activities on ground with distinctly different logics in mind. Fig. 1 depicts how the different conceptualizations diffused through time across the literature on the basis of a citation analysis. It shows the main citation paths through the reference sections of this set of publications and draws a conceptual 'tree of life' representing the lineages and legacies of different ways of thinking about experimentation. In the following section we will first provide a more in-depth reflection on the five main notions of experimentation and then discuss in more detail each of these conceptualizations. We illustrate our claims through canonical examples of actual real-life projects that feature in empirical literature.

3.1. Niche experiments

Much of today's research on sustainability transitions has its roots in the 1990s with the socio-technical experimentation as a center piece of the Strategic Niche Management (SNM). With its theoretical foundations in evolutionary economics and constructivists science and technology studies (i.e. major citations to Dosi, 1982 and Nelson and Winter, 1982),[5] SNM is based on the observation of an abundance of novel technologies with clear benefits for society being developed in R&D labs but failing to make it to the market because of interrelated social and technical factors. The factors decisively shape the selection environments embodied in so-called regimes (Geels, 2002; Kemp et al., 1998). These socio-technical regimes are complex configurations of three interlinked dimensions: network of actors and social groups, formal, normative and cognitive rules that guide the activities of actors and material and technical elements (Geels, 2004). They form the core of socio-economic structure, which shapes stability and continuity, but also form barriers to structural change towards sustainability. To facilitate a shift from an incumbent socio-technical regime to a more sustainable one (a transition), SNM assumes that creating new technological niches through protective policy measures and strategically exploiting existing market niches can facilitate this innovation journey. Niches are the loci where radical (as opposed to incremental) innovations can develop without being subjected to the harsh selection pressures of the prevailing regime. They are spaces that allow nurturing and experimentation with the co-evolution of technology, user practices, and regulatory structures (see Schot and Geels, 2008 for an overview). Technological niches may develop into market niches. The process through which niche experiments can come to influence regimes is called 'upscaling' (Jolly et al., 2012) or 'empowering' (Smith and Raven, 2012). This comprises all activities aimed at embedding of the experiment in regime-level structures (or transforming them), gaining structural support, involving key regime-players, overcoming barriers and making experiment part of a broader process of change (Jolly et al., 2012; Wilson, 2012).

The normative orientation of niche experiments is thus the creation of market niches as part of processes towards broader regime shifts. Actors who are outsiders to the incumbent regime are considered critically important. Great emphasis in SNM is put on the role of users in niche experiments. Nevertheless, the lessons learned about the nature of experimentation from early empirical research showed that "we were certainly over-optimistic about the potential of SNM as a tool for transition …. The experiments were relatively isolated events [and] there are limits to the power of experiments. Only occasionally will an experiment be such a big success that it will influence strategic decisions. Experiments may tip the balance of decision-making, but they will not change the world in a direct, visible way … Experiments influence the world but do not bring particular futures about. Their influence is more indirect." (Hoogma et al., 2002: 195–196). In line with this feat of reflexive criticism, later work on SNM studied not only individual user-oriented experiments, but also their relation to broader niche-building activities (Geels and Raven, 2006).

Early SNM work analyzed niches and niche experiments by studying the learning processes, network formation and articulation of expectations. More recently, the analytical emphasis in niche experiments has expanded to include conceptualizations of protective space itself (Smith and Raven, 2012). This conceptualization emphasizes three processes which are key to the protection of experimentation: shielding (a process that holds off the selection pressures in an active or passive way), nurturing (a process that supports the development of path breaking innovation) and empowering (a process that makes niche innovations competitive vis-à-vis regimes).

The development of biogas projects in Denmark illustrates how the notion of niche experiment is put to work for empirical analysis

[5] The protocol-driven search efforts have certain limitations. Some publication types (e.g., older journal articles, PhD theses, books and book chapters) are underrepresented in the STRN and Scopus databases implying that certain key publications were not found in this way. Other key publications were not found through the protocol driven search effort because they mobilize other terminology to talk about experimentation in their title or abstract such as pilot project, initiative and only later in the body text the term 'experiment' is used interchangeably. The downside of scoping for the notion of experiment in the body text and include all publications that mobilize this notion at some point is that a far too big sample is obtained which includes a lot of contributions not predominantly about experimentation as such. Because of these limitations, we chose to proceed with the initial protocol and add additional publications based on our further search efforts and personal assessment. It could be argued that this type of effort runs the risk of undermining the 'systematic' character of this review, lacks methodological rigor and is biased. Nevertheless, we believe that our pragmatic choice has paid off and that the eventual sample of 170 contributions we obtained through this combination is more comprehensive than any sample that we could have obtained by relying only on either a quantitative data-driven protocol or an unstructured qualitative search effort.

[6] For a schematic overview of our search efforts see Appendix I. For complete overview of our sample of 170 contributions see Appendix II.

[7] For an overview see Appendix III.

[8] For an overview see Appendix IV.

Please cite this article as: Sengers, F., et al., Experimenting for sustainability transitions: A systematic literature review, Technol. Forecast. Soc. Change (2016), http://dx.doi.org/10.1016/j.techfore.2016.08.031

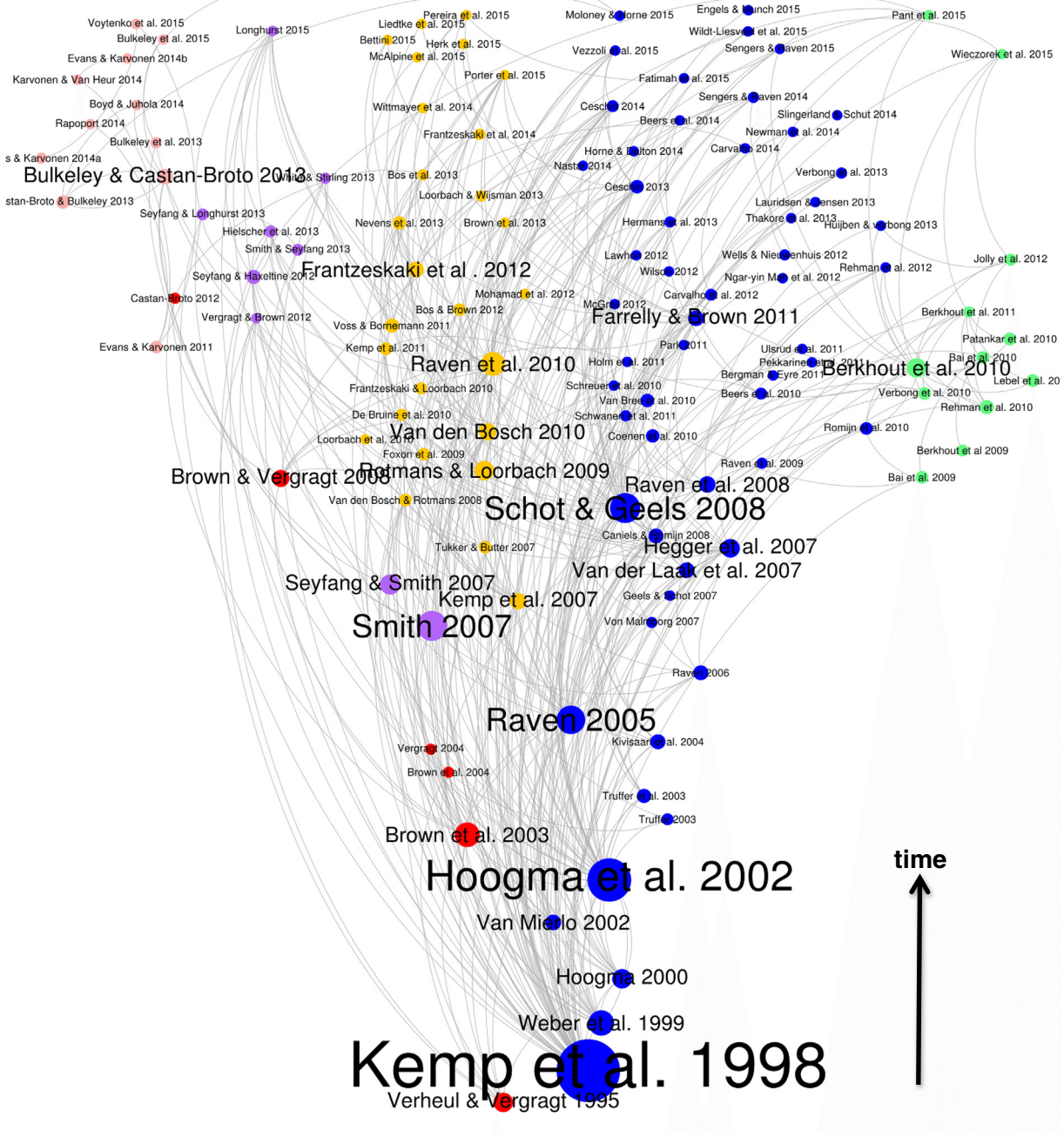

Fig. 1. Visual overview of 170 publications on experimentation through time in the Sustainability Transitions literature. Node sizes are proportional to the number of times a publication is cited within the sample and colors represent the dedicated terms that have been coined to distinguish been various types of experiments: blue = niche experiment; red = bounded socio-technical experiment; yellow = transition experiment; green = sustainability experiment; purple = grassroots experiment; pink = emerging contributions urban experimentation such as urban climate change experiment & urban living lab).

(Raven, 2005). Initially, farmers in the 1970s and 1980s responded to the global oil crisis by tinkering with biogas technology on their own farms, but with little success. In the mid-1980s the Danish government started to act more pro-actively as a strategic niche manager when it established a long-term policy program for biogas technology. This policy initiative shifted attention towards more centralized forms of biogas technology. The so-called biogas action program initiated a long-term development program organized around the establishment of more than 20 centralized biogas plants. The program orchestrated a heterogeneous network of both outsiders and insiders to the energy regime, including farmers, biogas technology suppliers, plant operators, municipalities, academics and policy actors. Social learning processes were facilitated through regular meetings, which increasingly give rise to shared expectations around socio-technical designs of biogas plants and the ways in which they could contribute to environmental challenges in energy, agricultural and waste regimes.

3.2. Bounded socio-technical experiments

Research on bounded socio-technical followed directly from the earlier work on what was then called 'social experiments' (Verheul and

Vergragt, 1995).[9] This notion surfaced when the SNM approach was being developed in the 1990s as a way of criticizing its central focus on technology. The social experiment and the idea of 'social niche management' emphasize the role of civil society and the process of building a social network of diverse technical- and non-technical actors. What followed later under the explicit header of bounded socio-technical experiments (BSTE for short) took the idea of the social experiment a step further with a clearer and more elaborate set of delineations and case studies to back it up (Brown et al., 2003). In contrast to the notion of the niche experiment, which is rooted in evolutionary and STS thinking, the BSTE draws on the social learning literature with most references to Argyris and Schön (1978) and Bandura (1977). To qualify as a BSTE, the initiative has to be recognized as being an experiment by at least some of the participants. And, as the name suggests, it attempts to introduce a new technology or service on scale bounded in space and time. It features a small number of users, often a geographically delineated community, and takes around five years.[10]

A good example of a BSTE is the set up of a zero-fossil-fuel residential building in a gentrifying neighborhood in 'blue collar' South Boston (Brown and Vergragt, 2008). The developer's ambition was to innovate in three areas: product (the building by use of as many cutting edge energy efficient technologies as possible), process (design and construction by assembling heterogeneous team, including potential residents, who interacted in a creative manner), and end use (life in the building by planning roof gardens or car sharing). The participants were expected to acquire a fresh perspective on their occupancy and, as a way of scaling up, to forward the experiences to others. This initiative qualifies as a BSTE because it is bounded to a specific area and community and because it emphasizes the importance of higher order learning, which occurred at the individual- as well as team level at four levels: problem solving, problem definition, dominant interpretative frame and worldview. Brown and Vergragt follow the minute details of the project by mapping and monitoring the interactions between a heterogeneous team of individuals, who play "their roles in a drama of sorts" as changes in the team's problem definitions and interpretation take place.

3.3. Transition experiments

Transition experiments are defined as a specific type of innovation projects with the aim to proactively explore radically new ways to meet societal needs, such as the need for energy, mobility or health care (Van den Bosch and Rotmans, 2008). They aim at solving persistent societal problems and, contrary to much previous work on niche experiments, are therefore not limited to technological change or environmental sustainability (Van den Bosch, 2010). They have been developed in the context of Transition Management approach (TM), which is aimed at influencing and directing sustainability transitions and has its roots in the complex system theory and evolutionary theory. The most references to the non-transition literature are made to Kauffman's (1995) work on complexity. Although TM consists of a deliberate attempt to bring about structural change in a stepwise manner, it does not attempt to achieve a particular transition goal at all cost. Rather, it utilizes the existing dynamics and re-orients it to transition goals chosen by society. The goals and policies to further these goals are not set into stone but constantly assessed and periodically adjusted in development rounds. Transition experiments are thus considered tools of TM.

The normative orientation of transition experiments is stimulating transitions towards societal goals. The analytical emphasis of transition experiments is on three processes: deepening, broadening and scaling up. Deepening refers to learning about the experiment and its (restricting) conditions. Deepening can be stimulated by: providing (financial, juridical and mental) space for setting up and conducting transition experiments in specific contexts; facilitating social learning; providing support, to overcome barriers, stimulating adequate monitoring and evaluation. Broadening concerns learning from related experiments or similar experiments in new contexts. It can be stimulated by: providing resources to replicate radically new practices in different contexts; facilitating interactions between similar experiments; stimulating network building; sharing learning experiences within a domain and stimulating linkages with adjacent domains. Scaling up relates to learning about regime change and (use of) broader developments (such as crises or world debates). It can be stimulated by: selecting and supporting frontrunners with the motivation and ability to experiment *and* scale up; balancing between providing protection from the regime and directly involving regime-actors who have the willingness and power to change existing structures (e.g. financial structures, regulation); realizing agreements with the regime; actively feeding back learning, experiences to the regime (Van den Bosch, 2010: 187). Frontrunners are thereby critical in transition management and experiments. The TM literature very specifically prescribes that these should not be usual stakeholders but individuals that are engaged with the societal challenge that is driving the experiment (e.g. sustainability), who have new ideas and are able to transcend organizational boundaries. Frontrunners should get together in a so-called transition arena, the outcome of which includes a portfolio of transition experiments that fit within the developed societal vision and pathways. To operate optimally the arena needs frontrunners with complementary backgrounds ranging from business, citizens, NGOs, science, government, art, media, religion etc. and matching competencies: mix of networkers, innovators and communicators.

An example of a transition experiment is the Transition Programme in Long-term Care (2007–2010) initiated by the Dutch Ministry of Health, Welfare and Sports and the Dutch care sector organizations. The programme was run by the Dutch Research Institute for Transitions (DRIFT) in collaboration with health care experts (CC Care Advisors) and organizational management (Ernst & Young). This programme qualifies as a transition experiment because it was initiated in practice and the Transition Management (TM) was applied as the central steering approach. The aim was to enable the care sector to fulfill the societal need for long-term care in the Netherlands in a radically different way. Its central focus was to explore and learn about radical innovations in health care, in a real-life context in which the end user is central. A total of 26 experimental projects were initiated by the frontrunner care institutes from all over the Netherlands and a transition arena was set up. The frontrunners participating in this arena developed a problem definition, a sustainability vision and transition pathways for long-term care (Transition Arena Care 2009). A number of learning

[9] Philip Vergragt played a central role in coining both the concept of the social experiment as well as the bounded socio-technical experiment. He notes: "we wrote [the paper that coins the notion of social experiment] as part of an EU-funded project called SMEC (Social Management of Environmental Change)". In those days I came already to the conclusion that too much emphasis in SNM was laid on technological rather than social innovations; so we invented the term "social niche management" as a sort of alternative. Later we developed that further in our papers of the early 2000s on Bounded Socio-technical Experiments; so in a way BSTE developed from Social Niche Management; however we emphasized less the "management' and more the role of social learning" (Vergragt, 2014, personal correspondence). A good example of an initiative labeled as a social experiment (the BSTE precursor) is the development of the Greenfreeze refrigerator as portrayed by Verheul and Vergragt (1995).

[10] This is more specific than in the case of the niche experiment. According to Brown and Vergragt (2008) existing environmental projects can be 'turned into' BSTEs, when learning is enhanced and monitored as a part of action research. Along similar action research lines, proponents of Transition Management also argue that technical projects can be turned into transition experiments when transitions researchers are embedded (Van den Bosch, 2010). In SNM research, on the other hand, definitions on what exactly constitutes an experiment are not so strict (basically the researcher only needs to show convincingly that the hands-on project to be studied is part of a socio-technical configuration that presents an alternative to the incumbent socio-technical regime, which is also to be characterized by the researcher him/herself). But despite some differences, there are also many similarities between BSTEs, niche experiments and transition experiments. Most notably perhaps, they are explicitly framed as concrete socio-technical projects conducted as part of an incremental strategy to help overcome the resistance of dominant unsustainable socio-technical systems or regimes. Reflexive higher order learning is the most important theme in BSTE analyses, but it also features prominently in SNM's niche experiments where (learning is one of the three core processes) and in TM's transition experiments (especially in the process of 'deepening' related to social learning).

Please cite this article as: Sengers, F., et al., Experimenting for sustainability transitions: A systematic literature review, Technol. Forecast. Soc. Change (2016), http://dx.doi.org/10.1016/j.techfore.2016.08.031

experiences regarding deepening, broadening and scaling-up were drawn and suggested for use by other transition experiments (Van den Bosch, 2010).

3.4. Grassroots experiments

Grassroots experiments refer to networks of activists and organizations generating novel bottom–up solutions for sustainable development; solutions that respond to the local situation and the interests and values of the communities involved. They are thereby motivated by the social needs and ideology. In contrast to mainstream business greening, grassroots initiatives operate in civil society arenas and involve committed activists experimenting with social innovations as well as using greener technologies (Seyfang and Smith, 2007: 585). The institutional forms for grassroots innovative niches differ from those of conventional innovations (firms) and include: cooperatives, voluntary associations, informal community groups or social enterprises. According to authors, grassroots innovation may take various forms: organic gardening cooperatives, low impact housing or farmers' markets. The concept has been developed using niche based approaches as proposed by Hoogma et al. (2002) and Schot et al. (1994) and multi-level socio-technical change (Geels, 2002) but it also has roots in the non-sustainability transition literature with most references to Douthwaite (2002). The normative orientation of grassroots innovation is a more inclusive form of strategic green niche development beyond the conventional scope of formal policies and markets. There is no pronounced and widely used analytical emphasis in studying grassroots innovations. Earlier, Seyfang and Smith (2007) studied grassroots innovative potential by evaluating intrinsic benefits (when an experiment is valued for its own sake and does not seek to change regime) and diffusion benefits (when it is intended to contribute to wider transformation). More recently Seyfang (2010) proposed the sustainable consumption indicators developed based on New Economics approaches to sustainable consumption[11] including: localization; reduction of ecological footprint, community building, collective action, new social infrastructure. Other contributions such as by Seyfang and Haxeltine (2012) use the three niche processes of learning, expectations and networks to analyze the niche development potential.

An example of grassroots experimentation can be found in the guise of the Transition Towns movement (TT). In this case each local civil-society group joining the movement and setting up initiatives and programs in their own locality can be said to qualify as an experiment (Seyfang and Haxeltine, 2012). These groups aim to provide a local response to the challenges of climate change and peak oil and by creating an alternative niche of new infrastructure and practices, which involves empowering the public and engaging them in a transition to a low carbon economy (Hopkins, 2008; Seyfang and Haxeltine, 2012). TTs concern various local activities such as establishing community-owned renewable energy companies, promoting locally grown food, garden sharing, encouraging energy conservation, exemplifying low-carbon living and reusable shopping (Hopkins, 2008). The initial idea was developed by permaculture teacher Rob Hopkins and his students in 2005 and is growing ever since. There are a number of TTs which are supported by a Transition Network Ltd., a formal coordination body that also endorses local groups that meet their official requirements. Strategic achievements of TTs include establishment and maintenance of supportive communities around these activities, building links with other local groups and government, awareness raising and community engagement activities. Seyfang and Haxeltine (2012) report that the majority of local groups (89%) are set up by individual citizens coming together to form a TT while 19% had pre-existing groups involved in getting set up. None were started by local councils, which validates the claims that TT is a true citizens' movement, generating energy and action from the grassroots. In the case of this experiment the SNM theory is deployed to make practical recommendations for this initiative to move beyond its niche and suggestions for SNM theory refinement made. It is argued that to better explain the development and broader impacts of grassroots innovations, SNM needs to pay more attention to role of identity and group formation and how social practices change in grassroots innovations.

3.5. Sustainability experiments

Sustainability experiments are planned initiatives that embody a highly-novel socio-technical configuration likely to lead to substantial (environmental) sustainability gains (Berkhout et al., 2009). They are experimental tests of new sustainability transition ideas. The ideas are *highly novel* meaning that they radically differ from the known and prevailing solutions and ways of providing human needs within a specific context. They are *planned*, which implies that they are conscious choices and not accidents or accidental occurrences. The reference to *socio-technical* configuration suggests that they are socio-technical in nature, not taking place in a lab, but in a societal context. Sustainability experiments are also strongly goal oriented. They are expected to lead to *substantial sustainability gains*, which encompass mostly environmental, but also social and economic aspects of development. By this sustainability experiments deliberately contribute to a broader vision of sustainability transition and are associated with alternative sustainable development pathways. Finally, sustainability experiments may result from activities at various societal levels. They may be top-down governmental actions set to support the process of transition or grassroots type of innovations. Hence, sustainability experiments may exhibit features of various types of experiments that have been described in the system innovation literature (Wieczorek et al., 2015).

The idea of sustainability experiments emerged in the context of debate about alternative development pathways in developing countries (Berkhout et al., 2009, 2010, 2011). Conventional development paradigms argue that developing countries follow stages of development of the developed economies and over time converge in economic structure, growth, productivity and environmental footprint (Abramovitz, 1986; Gerschenkron, 1962; Kuznets, 1966; Rostow, 1960). Research in Asian developing economies identified a great number of local innovative projects for sustainability that draw on transnational flows of knowledge, technology, capital, institutions or actors. The normative orientation of sustainability experiments is therefore sustainability gains. Avoidance of environmental convergence is what is observed theoretically. Analytical emphasis is put on 'transnational linkages', which were found important for stimulating sustainability oriented experimentation by motivating local capability formation and thereby contributing to development pathways that defy the traditional growth models theorized in the literature on catch-up (for a recent overview see Wieczorek et al., 2015).

An example of a sustainability experiment is Aurore Solar Home Systems (SHS) project in Tamil Nadu, India, in 2004 (Wieczorek et al., 2015). The main objective of this experiment is combined socio-economic and environmental sustainability based on replacing the use of diesel with solar energy. The SHS systems in the project provided brighter and safer light and they replace unhealthy kerosene lamps and candles, which results in saving of about 1300 CO_2 tons per year. This experiment was in many ways firmly embedded in a web of transnational linkages, which is reflected in the large number of international actors involved (e.g. software provider WIPRO, infrastructure supplier

[11] An alternative theoretical approach to environmental governance and sustainable consumption based on combined insights from ecological economics, institutional economics, political economy and behavioral economics (Boyle, 1993; Ekins, 1986). It argues that economics has intrinsic foundations in environmental and social contexts, so sustainability should primarily be aimed at well-being rather than at economic growth (Jackson, 2009). It also emphasizes the usefulness of decentralized social and economic organization and local self-reliance for protection of local environments and economies from the negative impacts of globalization (Jacobs, 1984; Schumacher, 1993). New Economics adopts a 'Spaceship Earth' view of the environment, which argues that resources are finite, and functioning ecosystems are critical for our survival.

Please cite this article as: Sengers, F., et al., Experimenting for sustainability transitions: A systematic literature review, Technol. Forecast. Soc. Change (2016), http://dx.doi.org/10.1016/j.techfore.2016.08.031

SREI, international NGO Greenpeace, multinational industries Bharat Heavy Electricals and Tata BP Solar, and even the initiator Auroville Foundation employs various foreign experts). The project was awarded a 2004 Ashden Award and recognized by UNDP (an institutional transnational linkage). Funds were provided by the National Ministry of Renewables and the project was replicated and expanded quantitatively at a national level. Together with many similar initiatives in SHS it contributes to the emergence of a SHS trajectory in the solar photovoltaics energy that serves the needs of mainly rural communities. This experiment is an example of locally driven but transnationally informed initiative. The various transnational linkages contribute to the enhancement of local capabilities and are ways of complementing for missing resources. They may thereby give rise to alternative development pathways that defy the convergence models of development envisaged by the mainstream literature.

3.6. Emerging conceptualizations on urban experimentation

While the experiment types discussed above provide a perspective on how transition scholars have thought about experimentation and its role, it is not an exhaustive typology. Although these are the five most established terms (or at least the most often cited ones), there are other terms that have not (yet) received as much of attention, but which are, nonetheless, worth mentioning. This includes terms such as 'governance experiments[12]' and 'real-world experiments[13]'. One set of promising new terms, which have gained traction in recent years, is specifically related to urban experimentation. Ideas around 'urban living labs' and the notion of 'urban climate change experiment' are important here. Drawing on Foucault's work on governmentality combined with ideas from transition studies, STS, policy mobilities and urban political ecology, Bulkeley et al.(2015) and Castán Broto and Bulkeley (2013) provide a large sample of 'interventions' where the notion of climate change is put to work locally in a variety of urban settings across the globe. Defined according to clear criteria, these interventions become climate change experiments when they are (1) purposive and strategic while recognizing the open-ended nature of socio-technical processes, (2) geared towards the mitigation of- or adaption to climate change, and (3) delivered in the name of an urban community (Bulkeley et al., 2015: 19). The work on urban living labs reflects the influx of ideas from urban studies and STS, as well as a large number of recent EU projects that frame experimental sites in cities in those terms (Karvonen and Van Heur, 2014; Voytenko et al., 2015). Because the above terms are rather new and therefore not yet prominently visible within the wider transitions literature, we have chosen not to include it at length in our review.

4. Discussion

4.1. Differences: variations along analytical dimensions

The overview of the different experiments presented in the earlier section reveals that the various terms of this typology differ on the following four dimensions.

First, each of the different terms in the typology has been coined with a particular *normative orientation* in mind. While experimenting for sustainability transitions implies purposive action towards a normative goal with regard to what a society should strive for, there are distinct differences in emphasis here. The variety in normative orientations reflects not only different ideals, but also different mechanisms through which these laudable goals are to be realized. For example, while the goal of sustainability experiments is to help achieve global environmental sustainability by strengthening green technological niches in developing countries, the goal of transition experiments is to stimulate transitions with more broadly defined societal goals in mind by starting with collective envisioning exercises.

Second, the concepts differ with regard to their *theoretical foundations*. All terms build on the notion of the original niche experiment as developed by Kemp et al. (1998) and Hoogma et al. (2002) and thus they are to a large degree ontologically similar and share many underlying assumptions such as those of reflexive governance, the Multi-level Perspective (Geels, 2002), Strategic Niche Management (Hoogma et al., 2002; Raven, 2005) and Transition Management (Loorbach and Rotmans, 2006). They reflect the origins of the ideas in the fields of science and technology studies (STS), evolutionary economics, and the history of technology. At the same time however, each of the terms also links to a unique combination of various other literature streams, analytical approaches, conceptual frameworks and theoretical backgrounds such as policy studies or development literature. These different ontological foundations and discursive focal points enable a particular, often complementary way of thinking about the role of experimentation.

Third, the terms differ in their *analytical emphasis*. By this we refer to the analytical concepts that are deployed by the researchers in studying particular types of empirical experiments and their role. For example, while the literature on niche experiments argues for an analysis of three core nurturing strategies: reflexive learning, alignment of expectations and the formation of actor networks, the literature on transition experiments features three different strategies for success of experimental projects: deepening, broadening and upscaling.

Fourth, the terms in the typology highlight the roles of different *main actors*. All concepts foreground certain types of initiators or actors who are otherwise critical for the success of the experiment. For example, while the Strategic Niche Management literature on niche experiments emphasizes the role of 'regime outsiders' (Van de Poel, 2000), the Transition Management literature on transition experiments talks about the importance of 'frontrunners' (Loorbach and Rotmans, 2010). Table 1 summarizes these findings and presents experiments' chronological evolution.

Tracing the different experiment-types through time, it could be argued that two main lines of thought have emerged. The first 'techno/managerial' line directly follows the initial work on niche experimentation, geared towards the creation of markets to upscale new green technologies — taking into account the importance of new socio-technical alignments. A second 'social/civic' line, which emerged soon after, then developed in response and emphasizes social innovation by engaged citizens. While the first line runs through the formulations of the notions of the niche experiment and the sustainability experiment, the second line is especially apparent in the emergence of the terms bounded socio-technical experiment and grassroots experiment, although individual papers and scholars often take nuanced position highlighting both technical and social developments, and taking into account complex relationships between formal, commercial actors such as industries and social actors such as NGOs or communities.[14]

When we look in more detail at the contributions on the various experiment-types and follow them though time it becomes apparent that there is an expansion in both scale and scope of the projects studied. While the earlier work has been characterized as foregrounding technological innovation and state-or-firm-driven experimentation

[12] In their conceptualization of governance experiments, Bos and Brown (2012) and Bos et al. (2013) follow Hoffman (2011) term to highlight the configuration of decision making by drawing on collaborative planning-, participation- and social learning literatures as a way to look beyond 'the disproportional focus on technical experimentation' of previous SNM accounts.

[13] In his conceptualization of real-world experiments, Schneidewind (2012) follows Gross and Hoffman-Riem's (2005) term on urban projects that involve the public in ecological restoration.

[14] The irony is perhaps that the most successful case of experimentation described with the SNM approach – in a way a foundational case study for the approach – was carsharing in the 1990s (Hoogma et al., 2002). As part of developing the SNM approach, Harms and Truffer (1998) and Truffer (2003) describe how citizen cooperatives in Switzerland were crucial for the development of this social innovation.

Please cite this article as: Sengers, F., et al., Experimenting for sustainability transitions: A systematic literature review, Technol. Forecast. Soc. Change (2016), http://dx.doi.org/10.1016/j.techfore.2016.08.031

Table 1
Conceptualizations of experiments in the sustainability transitions literature

Concept	Definition	Normative orientation (success factors)	Theoretical foundations	Analytical emphasis	Main actors
Niche experiment (1998)	"*A first step towards the development of a niche for new technologies and concepts. While an experiment is carried out under "laboratory-like" conditions, developing a niche means exposing the innovation step-by-step to real-world conditions. It involves a second stage of interaction with users and learning about constraints and requirements in a less isolated environment than an experiment … [Experimentation] stretches from the initial diffusion phase of a new technology to the time when a technology is sufficiently stabilized to survive without protection, to be replicated or extended and to induce a transformation of the technological regime*" (Weber et al., 1999)	Creation of market niches for radical innovation in the context of socio-technical transitions	CTA, STS and evolutionary economics, part of SNM/MLP	Three niche nurturing processes: (building networks, articulating expectations, second order learning)	Regime-outsiders, important role for users
Bounded socio-technical experiment (2003)	"*An attempt to introduce new technology or service on a scale bounded in space and time; a collective endeavor, carried out by a coalition of diverse actors, including business, government, technical experts, educational and research institutions, NGOs and others; a cognitive process in that at least some of the participants explicitly recognize the effort to be an experiment, in which learning by doing, trying out new strategies and new technological solutions, and continuous course correction*" (Vergragt and Brown, 2007)	Social learning towards new socio-technical systems	Social learning theory	Social learning processes	Civil society (but as part of a diverse set of stakeholders)
Grassroots experiment (2007)	"*Innovation is an experimental process …We use the term 'grassroots innovations' to describe networks of activists and organizations generating novel bottom–up solutions for sustainable development; solutions that respond to the local situation and the interests and values of the communities involved. In contrast to mainstream business greening, grassroots initiatives operate in civil society arenas and involve committed activists experimenting with social innovations as well as using greener technologies*" (Seyfang and Smith, 2007)	Inclusive green niche development with the potential for wider transformation of mainstream society	Social movement theory, draws on niche based approaches (i.e. SNM/MLP)	Sustainable consumption indicators: (localization, reduction of ecological footprint, community building, collective action, new social infrastructure)	Civil society (especially local communities, ecological citizens as initiators)
Transition experiment (2008)	"*An innovation project with a societal challenge as a starting point for learning aimed at contributing to a transition*" (Van den Bosch and Rotmans, 2008)	Stimulating transitions towards societal goals	Complex systems theory, part of TM	Three processes: (broadening, deepening, scaling-up)	Frontrunners as initiators
Sustainability experiment (2010)	"*A planned initiative that embodies a highly novel socio-technical configuration likely to lead to substantial (environmental) sustainability gains*" (Berkhout et al., 2010)	Sustainability gains, avoiding environmental convergence	Geography and innovation studies in developing country context, influenced by SNM/MLP	Transnational linkages: (actors, technology, knowledge, capital, institutions)	Multi-scalar innovation networks

within nation-states of the West (e.g. Hoogma et al., 2002; Kemp et al., 1998), more recent work branched out to include a larger variety of projects, mostly in urban settings (e.g. Bulkeley et al., 2015; Nevens et al., 2013), sometimes in the Global South (e.g. Berkhout et al., 2010; Jolly et al., 2012) and often foregrounding social innovation by engaged citizens (e.g. Brown and Vergragt, 2008; Seyfang and Haxeltine, 2012).

4.2. Commonalities: towards an overarching definition of experimentation

The overview of the 170 contributions on experiments in the Sustainability Transitions literature presented in the earlier section also reveals that a great variety of terms are mobilized to describe different types of experiments, pointing to subtle differences in focus and meaning. The scholars coin new terms on top of the pre-existing ones arguing that new conceptual vocabulary is required because the character of the initiatives they describe and, more importantly, the broader trend that the string of initiatives represent, is not adequately captured by the existing conceptual terminology.

Despite some shifts and distinctions highlighted so far, there is much more that binds this thinking about experimentation. Indeed, many real-life transition projects described in the literature as one type of experiment could easily be described in the terms of any of the other experiment types. This is apparent when we look, for example, at the literature on sustainability experiments, some of which are described with the classic SNM approach reserved for niche experiments (Verbong et al., 2010). Here we highlight a number of basic characteristics that all the definitions share. First is the interpretation of the experiment as a 'socio-technical' entity that has a rather specific meaning with regard to the introduction of new technologies or novel social practices into society. Second is the recognition that an experiment is an initiative in the context of *system innovation*, thus recognizing the material, institutional and cognitive obduracy of incumbent socio-technical systems central to our way of life. In that context experiments are important for structural change in two ways: to learn about the kind of structures that are prohibiting wider diffusion; and to act as a vehicle to actually initiate structural change on a small scale. Third, authors agree that an experiment is an attempt at trying something novel or different and that it is *challenge-led* which alludes to overcoming certain persistent societal problems associated with this obduracy and to the observation that experimentation in the context of transitions has a normative orientation (e.g. sustainability). Fourth, given this long-term and largely normative context, the transitions literature on experimentation further generally argues that experiments need to be *inclusive* of a variety of engaged social actors with the objective of connected *social learning* in relation to a new socio-technical configuration. Finally, whereas the scientific experiment that features in the natural sciences is geared to test something new in a taken-for-granted and completely controlled environment (i.e. a laboratory), the experiments that feature in the Sustainability Transitions literature are *practice-based*, which can be interpreted as something that is tested in a metaphorical 'laboratory' where a group of diverse social actors team up to test something new in a dynamic real-life social context with the eventual aim to achieve a societal transformation.[15] These metaphorical laboratories are sites of experiential learning where a course of action tentatively adopted without being sure of the outcome and thus where the ability to learn as well as previously gained experience can help the actors in the art of introducing a new technology of social practice. Given experiments' groundbreaking nature, various – sometimes conflicting – views on their function or meaning may be at play – resting in high levels of unpredictability about future socio-technical developments (*uncertainty*), or in deeper disagreements on the framing of problems and solutions as well as fundamentally different moral assessments of what is right and wrong (*ambiguity*) (see Stirling, 2010).

Based on these commonalities we propose an overarching definition of experimentation for sustainability transitions. An experiment can be conceptualized as *an inclusive, practice-based and challenge-led initiative designed to promote system innovation through social learning under conditions of uncertainty and ambiguity*.

4.3. Critical reflections

Overall, the literature on sustainability transitions paints a rosy picture of the experiments as a great source of hope. Experiments are often seen as the seeds of sustainable change that should be cherished and protected since they might flourish to transform incumbent socio-technical systems. They are geared to engender structural change by allowing the actors involved to learn about the kind of structures that are prohibiting wider diffusion of the tested socio-technical configuration by directly initiating change on the small scale of the experiment's direct environment. However, there are a few 'bones of contention' as well as number critiques that have been leveled against this way thinking. Major points of contention include whether to nurture experimental innovation in a protective space for a long time or to exposure of its vulnerabilities to regime selection pressures at an early stage (Hommels et al., 2007); whether to start experimenting straight away or to deliberate on a shared vision first (Schot and Geels, 2008); whether to emphasize consensus-oriented learning or productive disagreements and controversies in experiments (Hovell, 2008); and whether to rely on market-base policy experimentation or grassroots-civil society based approaches (Smith, 2007).

While experimentation is mostly perceived as something positive, its profusion should not be uncritically hailed as a sure blessing for transitions to sustainability. As the early work on SNM made convincingly clear, experimentation with new socio-technical configurations is a naturally occurring phenomenon in modern societies obsessed with progress and new technologies, but is it difficult to modulate – let alone steer – this overarching project in a sustainable direction (Schot and Rip, 1997). Too often, sustainability-oriented experiments are isolated events that fade into oblivion without any effect on incumbent regimes (Hoogma et al., 2002). Backed by meaningful and enduring state support, some welfare states (most notably Denmark, Sweden and Germany) have become world leaders in the manufacturing and adoption of important green technologies, while others feature low levels of reliable government support and seem to be lost in a labyrinth of experimental paths. The Netherlands is a case in point: an explosion in creative new business models applied in small-scale green energy initiatives has taken place in the country (Schwenke, 2014), but its renewable energy shares remain much lower than in surrounding countries (IEA, 2014). Those who claim to support transitions to sustainability should not lose themselves in the rhetoric the creative profusion of experimentation, but also confront the obduracy of incumbent regimes through far less sexy policy- and regulatory measures. If actors can gain legitimacy by cloaking themselves in experimentation-speak without taking hard measures to dismantle incumbent regimes than they are frustrating rather than fostering sustainability transitions.

5. Conclusion: towards a research agenda

This paper provides an overview of how experimentation is conceptualized in the literature on sustainability transitions. Various types of experiments were identified in this literature (niche experiments, bounded socio-technical experiments, transition experiments,

[15] The sustainability transitions literature is partly informed by earlier Science and Technology Studies (STS) contributions. STS scholars have long since argued that the ideas of 'laboratory' and 'experiment' have ventured outside of the their natural science confines and invaded society at large, thus blurring the strict lines between the privileged scientific knowledge and the pragmatic knowledge of everyday life (for a comprehensive overview see Karvonen and Van Heur, 2014). As Bruno Latour (2004:16) argued: "we are all engaged into a set of collective experiments that have spilled over the strict confines of the laboratories … on matters as different as climate, food, landscape, health, urban design, technical communication and so on. As consumers, militants, citizens, we are all now co-researchers".

Please cite this article as: Sengers, F., et al., Experimenting for sustainability transitions: A systematic literature review, Technol. Forecast. Soc. Change (2016), http://dx.doi.org/10.1016/j.techfore.2016.08.031

sustainability experiments, grassroots experiments as well as new conceptualizations of experiments in urban settings) each with their own normative orientations, theoretical foundations, analytical emphases and corresponding actor coalitions. Despite these differences there is much more that binds these experiment types and an overarching definition of experimentation in the context of sustainability transitions was formulated. An experiment can be conceptualized as 'an inclusive, practice-based and challenge-led initiative designed to promote system innovation through social learning under conditions of uncertainty and ambiguity'. It is clear that experimentation is a long-standing concept that started with a focus on their role in creating niches for sustainable technologies and that, more recently, alternative conceptualizations and promising new lines of thought were developed as scholarly work on the topic expanded. All of this signals a bourgeoning field of research, which is likely to expand both conceptually and empirically in the future.

With the future in mind, we want to end by sketching out promising avenues for further exploration. Based on our findings as well as recent formulations of research agendas for the field of Sustainability Transitions as a whole (STRN, 2010; Markard et al., 2012), a number of directions can be articulated as part of an emerging research agenda on the role of experimentation in fostering sustainability transitions.

The first promising avenue is concerned with and analysis of the different forms of *micro-politics, power and agency* in experimentation. We believe that there is scope to get under the skin of experimental projects in more detail and spell out the actual practices in experimentation. This includes the ways in which negotiations and struggles between actors involved in experimentation unfold and how their access to resources and respective relational positions shape their ability to influence the design and outcome of experimentation. This involves political questions of exclusion and social justice. Who becomes a participant in experimental activities and who is left out, and with what implications for the socio-technical design and outcome of experimentation in terms of the structural changes they help to shape? Who decides on who participates in experimentation and what are possible impacts for 'stakeholders' not involved (Shove and Walker, 2007)?

This would imply ethnographic research that unpacks which kind of social, economic and environmental interpretations of sustainability get promoted through experimentation and which ones are ignored. Addressing such questions can also counter-balance the prominent focus in the experiments literature on consensus-oriented, learning-based and shared visioning approaches to experimentation. Controversies and tensions are more often than not a central part of transition processes and experimental initiatives. A key-question is how the existence of controversies within experimental actor-networks may or may not productively generate structural change and what this implies for the role of experimentation in broader transition processes.

A second promising direction – the polar opposite of zooming in on the micro politics of one or a few experiments – is to move *beyond case-study based approaches*. This could be achieved by zooming out to engage with very large numbers of projects over multiple empirical domains, perhaps with the help of more quantitative tools. This may include research designs around bringing together great numbers of experiments in databases to find patterns (a few authors have already started to do this, see Castán Broto and Bulkeley, 2013; Wieczorek et al., 2015). This might allow us to more comprehensively identify crucial success- and failure factors of experiments (including the governance and policy conditions that triggered their design and implementation), conceptualize multiple experimental pathways (similar to the notion of transition pathways) and deploy network analysis to grasp how experiments are connected across locations and the kind of flows that go through them.

A third avenue that deserves further exploration is what we could label the *geography of experimentation*. This can be seen as part of the expanding research agenda on the geography of transitions (Truffer et al., 2015) and may include a variety of topics, some of which are already explored in more recent publications in the literature. Experimentation in urban contexts is a core topic that is currently explored by geographers and deserves further scrutiny (Bulkeley et al., 2015; Hodson and Marvin, 2010). Cities are sites of frantic interaction where multiple socio-technical systems connect, possibly providing opportunities for radical changes when tensions between multiple systems create windows of opportunity for agents of change. Conversely, inter-system alignments can also be sources of additional complexity and path-dependency, thereby limiting the opportunities for sustaining attempts for radical change. What role can city-officials and other change agents play in local experimental forms of transition management given these path-dependencies and complex settings?

Another geographical topic that deserves attention is the ways in which experiments are embedded (or fail to become embedded) in local contexts such as cities and regions. How do proximities in local and regional networks, infrastructures, resource endowments, political agendas, market structures, cultural settings and so on influence the form and outcome of experimental initiatives and, vice versa, how are these local spatial structures and processes reconfigured through experimentation? Such an agenda, when sensitive to the historical, path-dependent conditions in local or regional settings, would be able to improve our understanding of which experiments are more successful in some place than in others (Coenen et al., 2012).

A related interesting topic to be explored in more detail is the ways in which experiments become connected across different spatial scales, perhaps through the connections facilitated by a set of highly mobile change agents. Research has empirically demonstrated that while local or national actors often initiate experimentation, transnational linkages in experimentation are omnipresent in experimentation, in particular in the context of the Global South (Sengers and Raven, 2015; Wieczorek et al., 2015). The ways in which these multi-scalar structures influence experimentation positively or negatively, and the kind of resources that flow through them, deserves further attention, including a better understanding of how experimental activity can diffuse across scales.

A fourth promising avenue for further exploration is concerned with *the role of business* in experimentation. Several domains that are core to transition research on experimentation – such as renewable energy, electric mobility or organic food – have moved beyond the early phases of niche creation in the 1990s and are now more established industrial sectors. An increasingly prominent question is how conventional firms can generate green growth and benefit from these new 'clean-tech' opportunities. This includes looking at the role of large incumbents as well as green challengers (Hockerts and Wüstenhagen, 2010; Smink et al., 2013; Loorbach and Wijsman, 2013). A key question is also how (under which conditions) incumbent firms may benefit from participating in experimentation, and how – for better or worse – their participation is changing the nature of experiments (from radical, outsider experiments to more hybrid forms of experimentation bridging the niche-regime divide). Besides studying conventional firms, looking at the business-side of experimenting for sustainability transitions could include the application of management studies perspectives on the role of 'social entrepreneurs', local communities and engaged citizens who are organizing themselves in novel ways, coming up with new 'business models' and finding new ways of 'creating shared value' (Boons and Lüdeke-Freund, 2013; Huijben and Verbong, 2013).

A final avenue for research relates to the theme of this special issue, namely *the welfare state*. Based on our findings and suggestions, we can make a distinction between experimenting for the transformation 'of' welfare states versus experimenting for transformations of societal functions 'in' welfare states.[16] Most contributions on experimentation in the transitions literature are geared to address the transformation of specific societal functions or sectors (mobility, energy, water, healthcare, etc.) and not the transformation of the welfare state as

[16] Recent research on urban transitions features a similar distinction (i.e. experimenting in the city vs the experimental city as such — see Evans et al., 2016).

Please cite this article as: Sengers, F., et al., Experimenting for sustainability transitions: A systematic literature review, Technol. Forecast. Soc. Change (2016), http://dx.doi.org/10.1016/j.techfore.2016.08.031

such. But there is nothing inherent in the concept that would limit such an extension. As we showed, transition scholars already extended the concept of experimentation from its technology-oriented beginnings into other social domains. Especially the work on transition experiments and governance experiments might be productively mobilized to address questions on experimenting for transforming welfare states.

With the welfare state increasingly under pressure, and with decreasing possibilities (and perhaps ambitions) of national state actors to shape sustainability transitions, an interesting question can be put forward: who will be the key actors in future experiments? Recent work on experimentation in transition studies has started to look beyond 'the national' (Raven et al., 2012). Instead of providing center stage to nation-states and national governments, it highlights the role and re-emergence of the city as an experimental arena to address persistent problems (Hodson and Marvin, 2010; Bulkeley et al., 2011, in particular see Bulkeley et al., 2015 on urban climate change experiments). Yet, national governments are still crucially important actors in enabling this experimentation in cities (Sengers and Raven, 2015).

Moreover, although the field of transition studies mostly started out with the study of experiments in North- and Western European countries with strong welfare state traditions (most early contributions in Fig. 1 highlight this), there are plenty of later contributions on experimentation in other nations (a significant part of the later contributions in Fig. 1, especially the green dots). Parts of the welfare state may have been dismantled or restructured in the wake of the Regan/Thatcher era in the US and the UK (Clayton and Pontusson, 1998), but many transition accounts feature thriving grassroots experiments and bounded-socio-technical experiments in these two countries to show how civil society has picked up the baton instead (e.g. Brown and Vergragt, 2008; Seyfang and Haxeltine, 2012; Seyfang and Longhurst, 2013; Vergragt and Brown, 2012).

Acknowledgements

We gratefully acknowledge the financial support from the Dutch Organization for Scientific Research NWO-WOTRO (project number W 01.65.330.00). We are also grateful to the anonymous reviewers for their insightful comments that helped us improve this article.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.techfore.2016.08.031.

References

Abramovitz, M., 1986. Catching-up, forging ahead and falling behind. J. Econ. Hist. 46 (2), 385–406.
Argyris, C., Schön, D., 1978. Organizational Learning: A Theory of Action Perspective. Addison Wesley, Reading, Mass.
Bandura, A., 1977. Social Learning Theory. Prentice-Hall, Englewood Cliffs, NJ.
Berkhout, F., Angel, D., Wieczorek, A.J., 2009. Asian development and sustainable socio-technical regimes. Technol. Forecast. Soc. Chang. 76 (2), 218–228.
Berkhout, F., Verbong, G., Wieczorek, A.J., Raven, R., Lebel, L., Bai, X., 2010. Sustainability experiments in Asia: innovations shaping alternative development pathways? Environ. Sci. Pol. 13 (4), 261–271.
Berkhout, F., Wieczorek, A.J., Raven, R., 2011. Avoiding environmental convergence: a possible role for sustainability experiments in latecomer countries? Int. J. Inst. Econ. 3 (2), 367–385.
Boons, F., Lüdeke-Freund, F., 2013. Business models for sustainable innovation: state-of-the-art and steps towards a research agenda. J. Clean. Prod. 45, 9–19.
Bos, J.J., Brown, R.R., 2012. 'Governance experimentation and factors of success insocio-technical transitions in the urban water sector'. Technological Forecastingand Social Change 79 (7), 1340–1353.
Bos, J.J., Brown, R.R., Farrelly, M.A., 2013. A design framework for creating social learning situations. Glob. Environ. Chang. 23 (2), 398–412.
Boyle, D., 1993. What Is New Economics? New Economics Foundation, London
Briner, R.B., Denyer, D., 2010. Systematic review and evidence synthesis as a practice and scholarship tool. In: Rousseau, D. (Ed.), Handbook of Evidence-based Management: Companies, Classrooms, and Research. Oxford University Press, pp. 328–374.
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. Chang. 75, 107–130.
Brown, H.S., Vergragt, P.J., Green, K., Berchicci, L., 2003. Learning for sustainability transition through bounded socio-technical experiments in personal mobility. Tech. Anal. Strat. Manag. 15, 291–315.
Bulkeley, H., Castán Broto, V., Edwards, G.A.S., 2015. An Urban Politics of Climate Change: Experimentation and the Governing of Socio-technical Transitions.
Bulkeley, H., Castán Broto, V., Hodson, M., Marvin, S., 2011. Cities and Low Carbon Transitions. Routledge, London and New York.
Castán Broto, V., Bulkeley, H., 2013. A survey of urban climate change experiments in 100 cities. Glob. Environ. Chang. 23, 92–102.
Chappin, E.J.L., Ligtvoet, A., 2014. Transition and transformation: a bibliometric analysis of two scientific networks researching socio-technical change. Renew. Sust. Energ. Rev. 30, 715–723.
Clayton, R., Pontusson, J., 1998. Welfare-state retrenchment revisited. Entitlement cuts, public sector restructuring, and inegalitarian trends in advanced capitalist societies. World Polit. 51, 67–98.
Coenen, L., Benneworth, P., Truffer, B., 2012. Toward a spatial perspective on sustainability transitions. Res. Policy 41 (6), 968–979.
Dosi, G., 1982. Technological paradigms and technological trajectories. A suggested interpretation of the determinants and directions of technical change. Res. Policy 11 (3), 147–162.
Douthwaite, B., 2002. Enabling Innovation: A Practical Guide to Understanding and Fostering Technological Change. Zed Books, London, England.
Ekins, P. (Ed.), 1986. The Living Economy: A New Economics in the Making. Routledge, London.
Garfield, E., 1972. Citation analysis as a tool in journal evaluation. Science 178, 471–479.
Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective case-study. Res. Policy 31 (8/9), 1257–1274.
Geels, F.W., 2004. From sectoral systems of innovation to sociotechnical systems. Insights about dynamics and change from sociology and institutional theory. Research Policy 33, 897–920.
Geels, F.W., 2013a. Reference list to transition publications, July 2013. Retrieved from http://www.transitionsnetwork.org/files/Reference%20list%20to%20transition%20publications.pdf (accessed 01–08-2014).
Geels, F.W., 2013b. Words From the Chairman in 10th STRN Newsletter, December 2013. p. 1.
Geels, F.W., Raven, R.P.J.M., 2006. Non-linearity and expectations in niche-development trajectories: ups and downs in Dutch biogas development (1973–2003). Tech. Anal. Strat. Manag. 18 (3/4), 375–392.
Gerschenkron, A., 1962. Economic Backwardness in Historical Perspective: A Book of Essays. Belknap Press of Harvard University Press, Cambridge, MA.
Gross, M., Hoffman-Riem, H., 2005. Ecological restoration as a real-world experiment: designing robust implementation strategies in an urban environment. Public Underst. Sci. 14 (3), 269–284.
Harms, S., Truffer, B., 1998. The Emergence and Professionalisation of Two Carsharing Cooperatives in Switzerland: A Case Study for the Project 'Strategic Niche Management as a Tool for Transition to a Sustainable Transportation System. EAWAG, Dübendorf.
Higgins, J.P.T., Green, S., 2008. Cochrane Handbook for Systematic Reviews of Interventions. Wiley, Chichester.
Hockerts, K., Wüstenhagen, R., 2010. Greening Goliaths versus emerging Davids — Theorizing about the role of incumbents and new entrants in sustainable entrepreneurship. J. Bus. Ventur. 25 (5), 481–492.
Hodson, M., Marvin, S., 2010. Can cities shape socio-technical transitions and would we know if they were? Res. Policy 39, 477–485.
Hoffman, M.J., 2011. Climate Governance at the Crossroads: Experimenting With the Global Response After Kyoto. Oxford University Press, Oxford.
Hommels et al., 2007
Hoogma, R., Kemp, R., Schot, J., Truffer, B., 2002. Experimenting for Sustainable Transport: The Approach of Strategic Niche Management. Spon Press, London.
Hopkins, R., 2008. The Transition Handbook: From Oil Dependency to Local Resilience. Green Books, Totnes, Devon.
Hovell, 2008
Huijben, J.C.C.M., Verbong, G.P.J., 2013. Breakthrough without subsidies? PV business model experiments in the Netherlands. Energy Policy 56, 362–370.
International Energy Agency, 2014. Energy Policies of IEA Countries — the Netherlands 2014 Review.
Jackson, T., 2009. Prosperity without Growth? The Transition to a Sustainable Economy. London, Sustainable Development Commission.
Jacobs, J., 1984. Cities and the Wealth of Nations: Principles of Economic Life. Random House, London.
Jolly, S., Raven, R., Romijn, H.A., 2012. Upscaling of business model experiments in off-grid PV solar energy in India. Sustain. Sci. 7 (2), 199–212.
Karvonen, A., Van Heur, B., 2014. Urban laboratories: experiments in reworking cities. International Journal of Urban and Regional Research 38 (2), 379–392.
Kauffman, S., 1995. At Home in the Universe: The Search for Laws of Self-organization and Complexity. Oxford University Press, Oxford.
Kemp, R., Schot, J., Hoogma, R., 1998. Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. Tech. Anal. Strat. Manag. 10, 175–196.
Kuznets, S., 1966. Modern Economic Growth: Rate, Structure and Spread. Yale University Press, New Haven.
Latour, B., 2004. Which Protocol for the New Collective Experiments? In: Schmindgen, H., Geimerand, P., Dierig, S. (Eds.), Kultur Im Experiment. Kadmos Verlag, Berlin, pp. 17–36

Loorbach, D., Rotmans, J., 2006. Managing transitions for sustainable development. In: Olshoorn, X., Wieczorek, A.J. (Eds.), Understanding Industrial TransformationViews From Different Disciplines. Springer, Dordrecht.
Loorbach, D., Rotmans, J., 2010. The practice of transition management: examples and lessons from four distinct cases. Futures 42 (3), 237–246.
Loorbach, D., Wijsman, K., 2013. Business transition management: exploring a new role for business in sustainability transitions. J. Clean. Prod. 45, 20–28.
Markard, J., Raven, R.P.J.M., Truffer, B., 2012. Sustainability transitions: an emerging field of research and its prospects. Res. Policy 41, 955–967.
Meadowcroft, J., 2011. Engaging with the politics of sustainability transitions. Environ. Innov. Soc. Trans. 1 (1), 70–75.
Nelson, R.R., Winter, S.G., 1982. An Evolutionary Theory of Economic Change. Belknap Press/Harvard University Press, Cambridge.
Nevens, F., Frantzeskaki, N., Loorbach, D., Gorissen, L., 2013. Urban transition labs: co-creating transformative action for sustainable cities. J. Clean. Prod. 50, 111–122.
Petticrew, M., Roberts, H., 2006. Systematic Reviews in the Social Sciences: A Practical Guide. Blackwell, Oxford.
Raven, R.P.J.M., 2005. Strategic Niche Management for Biomass. Technische Universiteit Eindhoven, Eindhoven.
Raven, R.P.J.M., Schot, J., Berkhout, F., 2012. Space and scale in socio-technical transitions. Environ. Innov. Soc. Trans. 10 (4), 63–78.
Rostow, W.W., 1960. The Stages of Economic Growth: A Non-Communist Manifesto. Cambridge University Press, Cambridge.
Schneidewind, U., 2012. Cities as "real-world laboratories" for system innovations — theories, models and empirical designs. 3rd International Conference on Sustainability Transitions. Copenhagen, 29–31 August 2012.
Schot, J.W., Geels, F.W., 2008. Strategic niche management and sustainable innovation journeys: theory, findings, research agenda and policy. Tech. Anal. Strat. Manag. 20 (5), 537–554.
Schot, J.W., Rip, A., 1997. The past and the future of constructive technology assessment. Technol. Forecast. Soc. Chang. 54 (2–3), 251–268.
Schot, J.W., Hoogma, R., Elzen, B., 1994. Strategies for shifting technological systems: the case of the automobile system. Futures 26, 1060–1076.
Schumacher, E.F., 1993. Small Is Beautiful: A Study of Economics as if People Mattered. Vintage, London (first published 1973).
Schwenke, A., 2014. Lokale (Burger) Energie-Initiatieven: Wind-en energie-coöperaties,Energie-Initiatieven — Overzicht 2014. AS-I search, Leiden.
Sengers, F., Raven, R.P.J.M., 2015. Toward a spatial perspective on niche development: the case of bus rapid transit. Environ. Innov. Soc. Trans. http://dx.doi.org/10.1016/j.eist.2014.12.003.
Seyfang, G., 2010. Community action for sustainable housing: building a low-carbon future. Energ. Policy 38 (12), 7624–7633.
Seyfang, G., Haxeltine, A., 2012. Growing Grassroots Innovations: Exploring the Role of Community-based Initiatives in Governing Sustainable Energy Transitions in Environment and Planning C: Government and Policy. 30 pp. 381–400.
Seyfang, G., Longhurst, N., 2013. Desperately seeking niches: grassroots innovations and niche development in the community currency field. Glob. Environ. Chang. 23 (5), 881–891.
Seyfang, G., Smith, A., 2007. Grassroots innovations for sustainable development: towards a new research and policy agenda. Environ. Polit. 16 (4), 584–603.
Shove, E., Walker, G., 2007. CAUTION! Transitions ahead: politics, practice, and sustainable transition management. Environ. Plan. A 39 (4), 763–770.
Smink, M.M., Hekkert, M., Negro, S., 2013. Keeping sustainable innovation on a leash? Exploring incumbents' institutional strategies. Bus. Strateg. Environ.
Smith, A., 2007. Translating sustainabilities between green niches and socio-technical regimes. Tech. Anal. Strat. Manag. 19 (4), 427–450.
Smith, A., Raven, R.P.J.M., 2012. What is protective space? Reconsidering niches in transitions to sustainability. Res. Policy 41 (6), 1025–1036.
Stirling, A., 2010. Keep it complex. Nature 468 (7327), 1029–1031.
STRN, 2010. A mission statement and research agenda for the Sustainability Transitions Research Network. Available online at http://www.transitionsnetwork.org/files/STRN_research_agenda_20_August_2010(2).pdf.
Truffer, B., 2003. User-led innovation processes: the development of professional car sharing by environmentally concerned citizens. Innovations 16 (2), 139–154.
Truffer, B., Murphy, J., Raven, R., 2015. Editorial EIST special issue 'the geography of sustainability transitions'. Environ. Innov. Sustain. Trans.
Van de Poel, I., 2000. On the role of outsiders in technological development. Tech. Anal. Strat. Manag. 12, 383–397.
Van den Bergh, J.C.M., 2012. EIST one year: something to celebrate? Environ. Innov. Soc. Trans. 4, 1–6.
Van den Bosch, S., 2010. Transition Experiments: Exploring Societal Changes Towards Sustainability (PhD diss.) University of Rotterdam.
Van den Bosch, S., Rotmans, J., 2008. Deepening, Broadening and Scaling up: A Framework for Steering Transition Experiments. Knowledge Centre for Sustainable System Innovations and Transitions, Rotterdam.
Verbong, G.P.J., Christiaens, W., Raven, R., Balkema, A., 2010. Strategic niche management in an unstable regime: biomass gasification in India. Environ. Sci. Pol. 13, 272–281.
Vergragt, P.J., Brown, H.S., 2007. Sustainable mobility: from technological innovation to societal learning. J. Clean. Prod. 15 (11–12), 1104–1115.
Vergragt, P.J., Brown, H.S., 2012. The challenge of energy retrofitting the residential housing stock: grassroots innovations and socio-technical system change in Worcester, MA. Tech. Anal. Strat. Manag. 24 (4), 407–420.
Verheul, H., Vergragt, P., 1995. Social experiments in the development of environmental technology: a bottom-up perspective. Tech. Anal. Strat. Manag. 7, 315–326.
Victor, L., 2008. Systematic reviewing. Social research update 54: 1–4. (retrieved from) http://sru.soc.surrey.ac.uk/SRU54.pdf (accessed 01–08-2014).
Voytenko, Y., McCormick, K., Evans, J., Schwila, G., 2015. Urban living labs for sustainability and low carbon cities in Europe: towards a research agenda. J. Clean. Prod. 123, 45–54.
Weber, M., Hoogma, R., Lane, B., Schot, J., 1999. Experimenting with Sustainable Transport Innovations: A Workbook for Strategic Niche Management. IPTS/University of Twente, Sevilla/Enschede.
Wieczorek, A.J., Raven, R., Berkhout, F., 2015. Transnational linkages in sustainability experiments. The case of solar PV in India. Environ. Innov. Soc. Trans. 17, 149–165.
Wilson, C., 2012. Up-scaling, formative phases, and learning in the historical diffusion of energy technologies. Energ Policy 50, 81–94.

Frans Sengers is a postdoctoral researcher in the Copernicus Institute for Sustainable Development at Utrecht University in the Netherlands. The connecting theme running through his work is transformative change in urban contexts, especially in Asian cities. A key question is how socio-technical experimentation, institutional change and path-dependent regimes in cities across the globe co-produce our urban future. His current post-doc research centers on eco-city and smart city developments, comparing current activities Europe and China. Before that time Frans completed his PhD thesis on the prospects for sustainable urban mobility in Thailand.

Anna J. Wieczorek is a researcher and a lecturer at the School of Innovation Sciences of Eindhoven University of Technology. For 12 years, she has run the Industrial Transformation Science Project of IHDP Program facilitating research on applying insights from the emerging stream of system innovation in the context of analyzing economic and environmental transitions occurring in developing Asia. Next to academic courses, she has designed and teaches professional trainings on sustainability transitions in the context of Climate-KIC and InnoEnergy-KIC. Her current work focuses on the role of experiments in inducing sustainability transformations both in established as well as in developing economies.

Rob Raven is designated chair in the UU strategic theme Institutions and full professor 'Institutions and Societal Transitions' at the Innovation Studies Department of Utrecht University. His current research agenda is focused on analysis of transformative change in urban context such as eco-cities and smart cities. A key question is how socio-technical experimentation, institutional change and path-dependent urban regimes co-produce the future of cities world-wide.

Please cite this article as: Sengers, F., et al., Experimenting for sustainability transitions: A systematic literature review, Technol. Forecast. Soc. Change (2016), http://dx.doi.org/10.1016/j.techfore.2016.08.031