Journal of Cleaner Production xxx (2017) 1–13

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Experiments in climate governance – A systematic review of research on energy and built environment transitions

Paula Kivimaa [a, b, *], Mikael Hildén [b], Dave Huitema [c, d], Andrew Jordan [e], Jens Newig [f]

[a] Science Policy Research Unit SPRU, University of Sussex, Jubilee Building, Falmer, Brighton BN1 9SL, UK
[b] Finnish Environment Institute, P.O. Box 140, 00260 Helsinki, Finland
[c] IVM Institute for Environmental Studies, VU University Amsterdam, De Boelelaan 1087, 1081 HV Amsterdam, The Netherlands
[d] Department of Science, Open University of the Netherlands, Valkenburgerweg 177, 6419 AT Heerlen, The Netherlands
[e] Tyndall Centre, University of East Anglia, Norwich, UK
[f] Leuphana University Lüneburg, Germany

ARTICLE INFO

Article history:
Received 28 January 2016
Received in revised form
26 October 2016
Accepted 5 January 2017
Available online xxx

Keywords:
Governance experiments
Experimentation
Transitions
Climate policy
Climate governance
Governance innovation

ABSTRACT

Experimentation has been proposed as a key way in which governance drives sustainability transitions, notably by creating space for innovative solutions to emerge. In seeking to bring greater coherence to the literatures on climate and sustainability governance experiments, this article reports on a systematic review of articles published between 2009 and 2015. Based on these results a new definition and typology of climate governance experiments is suggested. The typology distinguishes between the various purposes experiments can have, including niche creation, market creation, spatial development, and societal problem solving. It deepens the understanding of the diversity in experimenting by highlighting the salient features of different types of governance experiments. It can therefore guide future research to generate more cumulative research findings contributing to a better understanding of the role and outcomes of experiments in societal transitions. The findings also suggest that real transitions towards low-carbon and climate-resilient societies will require a systematic deliberate combination of different types of experiments.

© 2017 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

1. Introduction

Experimental approaches to governance have recently received increasing attention in the academic literature. Experimentation can challenge the *status quo* and enable the exploration of governance innovations, technologies and services in a temporary space (Sanderson, 2002; Berkhout et al., 2010; Heilmann, 2008). In the literature on sustainability transitions, experimentation is a key theme, with experiments often seen as a way of establishing niches, i.e. fringe spaces for emerging technologies or alternatives to current methods of governance (e.g. Schot and Geels, 2008; Berkhout et al., 2010; Frantzeskaki et al., 2012).

Experiments have also received political attention. One example is the Finnish Government Programme of 2015 that aspires to create a 'culture of experimentation' to strengthen policy development with extensive trials and several smaller experiments, systematic experimentation and a legal basis to facilitate the arrangement of experiments (Government Programme, 2015). Another example is the current UK Cabinet Office which has organised an open "governance lab". Previous UK governments have been keen on pilot projects and seen them as a way to engage in evidence based-policy making. Also urban living labs emphasising an experimental approach to governing cities (Voytenko et al., 2016) are increasingly popular. More generally, experiments have been advocated as a way to enhance the evidence basis underpinning policy interventions (e.g. Sanderson, 2002).

A particularly interesting context for experiments is climate governance. Experimentation is claimed to be better suited to address the multidimensional and complex nature of climate change than more traditional modes of governance (e.g. Castán

* Corresponding author. Science Policy Research Unit SPRU, University of Sussex, Jubilee Building, Falmer, Brighton BN1 9SL, UK.
E-mail addresses: p.kivimaa@sussex.ac.uk, paula.kivimaa@ymparisto.fi (P. Kivimaa), Mikael.hilden@ymparisto.fi (M. Hildén), Dave.Huitema@vu.nl (D. Huitema), A.Jordan@uea.ac.uk (A. Jordan), newig@uni.leuphana.de (J. Newig).

http://dx.doi.org/10.1016/j.jclepro.2017.01.027
0959-6526/© 2017 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

Please cite this article in press as: Kivimaa, P., et al., Experiments in climate governance – A systematic review of research on energy and built environment transitions, Journal of Cleaner Production (2017), http://dx.doi.org/10.1016/j.jclepro.2017.01.027

Broto and Bulkeley, 2013; Bulkeley et al., 2014a). Literatures on urban experimentation (Bulkeley et al., 2014a) and polycentric governance (Jordan et al., 2015) acknowledge the restricted ability of national and transnational governance structures to address global problems, even post the Paris Climate Agreement. There has also been an increasing upsurge of experimental actions by cities, regions, businesses and civil society organisations (Chan et al., 2015) that can be subsumed under the scope of climate governance experimentation.

The concept of experiments is used in very different ways by academics and policy makers. To begin with, there is much variety in the understandings of what constitutes an experiment (particularly in governance) and what types of experiments exist. Some academic authors tend to emphasise (only) novelty when they use the term (Hoffman, 2011), whereas others suggest that it only applies when a test is performed (McFadgen and Huitema, in progress). Tassey (2014) sees experiments as offering some flexibility and the opportunity to test novel policy options on a limited scale and that the interventions are at least to some extent reversible. In turn, Sabel and Zeitlin (2012: 1) emphasise the repetitive nature of experimenting and define experimental governance as "a recursive process of provisional goal-setting and revision based on learning from the comparison of alternative approaches to advancing them in different contexts".

Despite the centrality of experiments, De Bruijne et al. (2010, p. 276) have argued that the literature on sustainability transitions is *"vague and ambiguous with regard to how experiments should be set up and managed in practice to contribute to transitions*". This article argues that the inconsistent conceptualisation of experiments is inhibiting cumulative understanding across case studies. An additional problem is that normative values (what experiments should do) and positive analyses (of what they actually do) are often subtly interwoven in the writings on experimentation. Furthermore, Bos and Brown (2012) have stated that the transitions literature has paid disproportionate attention to technical experimentation, with a lacking focus on the dynamics of how governance experimentation unfolds. Kern and Howlett (2009) also point out that empirical studies of transition management have tended to focus on technically oriented experiments coupled with conservative funding criteria.

This article sets out to bring some order to the field by systematically exploring how the concept of experiments is used in the literature studied for this review. In this it also contributes to a call for more research on the outcomes of experiments (Bulkeley et al. (2014b) on urban experiments; Verbong et al. (2010) on Indian biogas experiments, Nair and Howlett (2015) on policy experiments in the water sector). It does so by reviewing experiments that were either deliberately conducted as governance experiments (e.g., trials with new measures, institutions or principles in the form of policy experiments in public or private governance) or as research experiments with the aim to inform governance. The academic literature included in the systematic review is scrutinised as to what contexts experiments have been undertaken in, and what outputs and outcomes they are reported to have generated.

Throughout, the aim is to learn from previous, in particular empirical, research on experiments with a view to advance the study of this diverse phenomenon. The discussion is based on a systematic review (Petticrew and Roberts, 2006) of experiments reported in published peer-reviewed journal articles, as the authors were not aware of previous systematic reviews on the topic during the time of the study. One of the aims is to derive a typology of experiments. To this end, specific questions were formulated:

- What is the nature and focus of experiments that link sustainability transitions to climate governance?
- What kind of outputs and outcomes do these experiments generate? And what is their specific role in low carbon or climate resilience transitions?

Particular attention is devoted to identifying *governance* experiments that may contribute to transitions, as this angle is largely absent from the transition literature (e.g. Bos et al., 2013). Heilmann (2008, p.2) stresses that governance experimentation refers to interventions done in a deliberate way, allowing for systematic learning. The systematic review informing this article therefore took into account both systematic experiments that variegate with governance measures, institutions, or principles (based on Kooiman, 2003), and experiments that potentially challenge or question existing governance structures and practices.

Section 2 begins by discussing the literature on experiments. The research approach and the case survey method are explained in Section 3, and Section 4 presents the findings of the systematic review. Section 5 discusses the findings, and Section 6 provides conclusions.

2. Governance innovation and transition experiments: background and theory

This article focuses on experiments in climate governance with respect to sustainability transitions. Following Kooiman (2003) governance is understood here as "*the patterns that emerge from the governing activities of social, political and administrative actors*" (Kooiman, 1993: 2). (See also Kohler-Koch, 1999: 14). Lange et al., 2013 stress that governance includes articulations of policy, politics and polity. Policy has been defined as *"a relatively stable, purposive course of action followed by an actor or a set of actors dealing with a problem or a matter of concern"* (Anderson, 2006: p. 6). Because of the close links between governance and policy, many governance experiments are often – but not always – also policy experiments. Experiments that successfully challenge existing policies may result in policy innovations, when inventions in, for example, policy design or implementation are taken into use.

Experiments can contribute in important ways to governance. They can either constitute (deliberate) interventions that aim at solving problems or developing new practices (as in pilots or demonstration projects), or they are conducted in order to learn about the effects of (limited) interventions for future (more large-scale) interventions. Their potential strength lies in the opportunity to tinker with new approaches, practices or institutions on a small scale and/or temporarily. They can circumvent or challenge dominant values and bring in new actors. Knowledge about how something (e.g. a technology, a service, a policy, etc.) 'works in the real world' is typically expected to be an output. This means that learning is an essential justification for experiments (cf. Kemp et al., 2007; Brown and Vergragt, 2008; Tassey, 2014). Experiments may also, for example, provide market impact data (Tassey, 2014), test and introduce a new technology or service (Brown and Vergragt, 2008), or identify governance problems and create cooperative networks or visions (Kemp et al., 2007). However, often experiments are also expected to create more long-term outcomes, for example, initiate a process of broader socio-technical change in markets or practices (e.g. Brown and Vergragt, 2008; Berkhout et al., 2010).

Linking experimentation to governance innovation is important, as governance choices (often embodied in public and private policies) are expected to affect behaviour, practices, investments and social and technological innovation to a large degree. Although they may not in the beginning impose significant changes in institutions, experiments – being more flexible and adaptive – do offer a way of dealing with uncertainty and variability, and, at the outset, have the

Please cite this article in press as: Kivimaa, P., et al., Experiments in climate governance – A systematic review of research on energy and built environment transitions, Journal of Cleaner Production (2017), http://dx.doi.org/10.1016/j.jclepro.2017.01.027

potential to avoid the limiting influence of technological and institutional lock-ins that inhibit transitions.

Governance (and policy) innovation can, in line with (Jordan and Huitema (2014) and Upham et al., 2014), be depicted as a broad concept referring to novelty in both processes (ways to govern and create outputs and outcomes) and their outputs (new goals, strategies, policy designs and instruments). This means that (1) innovation as a process change may, for example, increase flexibility for governance and policy, encouraging more experiments, or (2) governance experiments can lead to or refine governance innovations as an output. These outputs can be new goals, new instruments, or new types of leverage mechanisms or implementing organisations (Jordan and Huitema, 2014; Upham et al., 2014). For example, a series of experiments prepared the ground for adopting the European emission trading scheme (Hildén, 2014). To qualify as an innovation, a novel governance process, goal, instrument or implementing organisation, needs to be taken into use and be its 'first application' (Jordan and Huitema, 2014) typically in a given sector or country (e.g. Black, 2005). Broader socio-technical outcomes are the wider consequences of the policy outputs.

The sustainability transitions literature deals with how socio-technical systems can transform over time to become more environmentally sustainable through radical changes not only in technology but also in institutions, practices and culture surrounding the previously dominant technology (e.g. Markard et al., 2012). In the transitions literature, experiments have been defined as:

- "planned initiatives that embody a highly novel socio-technical configuration likely to lead to substantial (environmental) sustainability gains" and "represent small initiatives in which the earliest stages of a process of socio-technical learning takes place … [and] typically bring together new networks of actors with knowledge, capabilities and resources, cooperating in a process of learning" (Berkhout et al., 2010, p.262)"

In the literature, experimentation plays an important role in two different settings: (1) Experimentation as part of (bottom up) niche innovation, and (2) experimentation specifically initiated at a regime-level, which is considered the stable part of the socio-technical system (Geels, 2005, 2011). However, the literature often leaves the actual impact of experimentation in transitions implicit.

In the multilevel perspective (MLP) on transitions (e.g. Geels, 2005, 2011), innovation is considered to occur in protected niches through pursuing and testing radical novelties in real-world experimental projects (e.g. Schot and Geels, 2008). Facilitating and guiding such niche innovations towards sustainability is the objective of strategic niche management (SNM; e.g. Hoogma et al., 2002), a conceptualisation frequently associated with MLP. In SNM, niche experiments are expected to serve as "*a compass for guiding future regime transitions in sustainable directions*" (Smith, 2006). Upham et al. (2014, p. 779) argue that while many (sectoral) policy innovations occur at the regime level, "*the niche level can be depicted as consisting of small platforms for [climate policy innovation], with new technologies and solutions making new policies possible through demonstrating or testing policy inventions and innovation at small scales …*"

Experiments initiated at a regime level connect to a literature dealing with transition management (TM). TM is a particular normatively oriented strand of the transitions literature that proposes a 'tool kit' for governing transition to achieve radical change towards more sustainable systems of production and consumption. It differs from SNM by highlighting the importance of visioning before engaging in experimenting, thus, making experimenting more coordinated than SNM that emphasises unguided experimenting and the evolutionary nature of experimentation in providing variation of options (e.g. Schot and Geels, 2008). In TM, transition experiments "*may be initiated by the transition arena network as an outcome of the transition agenda …* [and] *focus (among other things) on new institutional arrangements that can enable new pathways or innovations benefiting sustainability.*" (Frantzeskaki et al., 2012, p.31). Thus, operational-level experiments are recommended to follow after transition arenas have identified problems and created a vision forward (cf. Kemp et al., 2007), key focus being delivering on sustainability aims, connecting actors, and producing social learning (Grin et al., 2010).

The in-built reflexivity of TM is expected to create space for experiments that facilitate the transition (cf. Voss et al., 2009), even if transition arenas as such do not (necessarily) have the formal powers of (mainstream) policy developers (e.g. Frantzeskaki et al., 2012). Transition experiments are expected to create outcomes through three different mechanisms: "*deepening (learning as much as possible from the transition experiment), broadening (repeating an experiment in an adjusted form in a different context) and scaling-up (embedding an experiment in the existing structures of the incumbent regime)*" (Grin et al., 2010, p.146). The extent to which experiments have empirically proved successful in these respects has, however, not received much explicit attention in the literature (Bos et al., 2013; Porter et al., 2015).

3. Methodological approach

Our systematic review targeted scholarly articles identified through Scopus.[1] To capture the most recent debate the search focused on studies published in the period 2009–2015 in social sciences and humanities. For replicability and ease of access, conference papers and book chapters were excluded from the analysis. Other exclusion criteria concerned randomised control trials, as the focus was on qualitative descriptions of real-world experiments. The caveat of such studies lacking rigorous experimental design is susceptibility to bias (Petticrew and Roberts, 2006) but their advantage is in providing narratives with insights into diverse experimental settings that for practical or political reasons cannot be carried out as a rigorous experiments.

"Experiment*" (with * indicating truncation to cover all variants) was used as a key search word, i.e. all articles that did not refer to experiment(s) or experimenting explicitly were excluded.[2] The other search words used were selected to link to climate change policy and governance with particular attention paid to energy and built environment transitions by including terms such as "energy efficiency", "low energy", "energy saving", "renewable energy", "mobility", "transport", "adaptation" and "transition" (see Appendix 1). The caveat of this study is that we did not use specific search words containing, for example, "agriculture", "food", "waste" or "water", although articles in these domains were not excluded from the study, if they came up in the searches using more general search words. While the number of hits was 174 in total, based on twelve different search word combinations, the content analysis of abstracts revealed that a large number of articles dealt with experiment as research design and not as an empirical topic of inquiry. Such articles were excluded from further analysis.

Through content analysis of abstracts, in total 25 scientific

[1] Scopus is the largest abstract and citation database of peer-reviewed literature. It contains publications by Elsevier, Springer, Wiley-Blackwell, Taylor & Francis, Sage, Emerald, Oxford University Press and several other publishers.

[2] While the authors acknowledge that terms such as 'pilots', could be used to describe a similar phenomenon as experiments, the purpose here was specifically to review research on what has been designated as experiments.

Please cite this article in press as: Kivimaa, P., et al., Experiments in climate governance – A systematic review of research on energy and built environment transitions, Journal of Cleaner Production (2017), http://dx.doi.org/10.1016/j.jclepro.2017.01.027

articles were identified that merited full-paper content analysis. Of these, 18 articles contained qualitative descriptions of 29 experiments that were scrutinised in the review. In addition, seven articles were included that either did not contain an actual experiment or that presented aggregated results of such a large number of cases that a detailed analysis was impossible. These articles were reviewed more generally in terms of how they defined experiments and what literature and sectors they referred to.

The core papers were then explored using case survey (Lucas, 1974) and systematic review (Petticrew and Roberts, 2006). The case survey method allowed a systematic and structured synthesis of *'previous case-based research, drawing on the richness of the case material, on different researchers and research designs … '* (Newig and Fritsch, 2009: 2). The risk of bias in summarising uncontrolled studies was recognised (cf. Petticrew and Roberts, 2006) and therefore no statistical analysis was attempted. The analysis was structured following the standard components of policy evaluation (i.e. inputs, outputs, outcomes, target group, process) (Vedung, 1997). Throughout, the unit of analysis was the experiment rather than the scholarly article, meaning that an article describing several experiments provided several units for the analysis.

A qualitative analysis was carried out to provide answers to preset categories that both described the nature of the experiment and evaluated it according to a number of criteria aiming for a large spread of categories (Table 1). The categories were selected on the basis of the authors' previous knowledge of experiments and socio-technical transitions as well as on the policy evaluation literature (e.g. Vedung, 1997). New categories were added inductively, when the analysis of the articles revealed missing but possibly important categories. The article used componential analysis in the case survey, i.e. a systematic search for attributes (components of meaning) associated with the experiments (Onwuegbuzie et al., 2012). To achieve this matrices describing the experiments were constructed to identify the differences among the subcomponents of the categories (Table 1).

Subsequently, typologies based on repeated instances were identified in each category. In addition, the broader set of papers that did not include empirical descriptions of experiments was reviewed to place the findings in a wider context. Investigator triangulation was used in that 2–3 people coded each article independently, and subsequently the first author merged the results. Differences in initial coding was treated as a reflection of uncertainty in the findings.

4. Results

The beginning of this section provides an overview of the experiments included in the systematic review, and responds to the first research question of the nature and focus of experiments. Sections 4.1 and 4.2 address the second question about the outputs and outcomes of experiments.

Out of the 25 reviewed articles, 19 made some connection to socio-technical transitions theories. Out of 29 experiments, 22 were connected to transitions, five engaging particularly with TM and seven referring to socio-technical or sustainability experiments in the context of SNM (Fig. 1). The non-transition experiments contained three strategic spatial planning experiments, and four experiments focusing on urban development. Of the more generic articles Deitchman (2014) focused on policy experiments, whereas Stewart (2012) mentioned experiments as a complementary form of governance to traditional regulatory and fiscal measures.

In terms of empirical content, the sectors covered the built environment, energy, transport, water, and community development (Fig. 2). Some climate relevant sectors, such as agriculture and food, were absent. While they were not specifically searched for, they were neither excluded from the scope of the study. The built environment related experiments ranged from stimulating new housing and construction (e.g. Holm et al., 2011) to energy efficiency retrofits (Bulkeley et al., 2014c). Many cases spanned the built environment and energy sectors, or were even broader.

Table 1
Analytical categories that were used to analyse the experiment cases.

Pre-set categories for case survey of experiments	
Main categories	Subcomponents
1. General categories providing background information	1.1 Definition of experiment used
	1.2 Related theory/literature
	1.3 Engagement of author with the experiment process
2. Empirical detail on the experiments	2.1 Type of experiment (as described by the authors of the case study articles)
	2.2 Objectives of the experiment
	2.3 Climate objective/sustainability objective (yes or no)
	2.4 Sector and focus of experiment
	2.5 Geographical location and scale
	2.6 Duration of the experiment
	2.7 Actors leading the experiment
3. Categories based on evaluation research (Vedung, 1997)	3.1 Inputs to the experiment (e.g. financial and human resources)
	3.2 Process (how experiment unfolds)
	3.3 Target actors of the experiment
	3.4 Outputs/outcomes (realised)
	3.5 Evaluation(s) carried out
4. Governance elements of the experiment	4.1 Link to governance (how presented in the article)
	4.2 Local/city government involved/national government involved (yes or no)
5. Transition elements of the experiment	5.1 Upscaling or transfer potential
	5.2 Learning processes
	5.3 Incremental vs. systemic change
	5.4 Drivers and triggering activities for initiating the experiment
	5.5 Reversibility and decision points after the experiment
	5.6 Level and nature of risk taking (financial and political)
6. Outcomes of the experiments	6.1 Policy and institutional change/new market or market change/new business practices/changed consumer or community practices/new technology/built environment and infrastructural change/changed discourse (yes or no)
	6.2 Innovation type: technological/social innovation/governance (as process or policy output) (yes or no)

Please cite this article in press as: Kivimaa, P., et al., Experiments in climate governance – A systematic review of research on energy and built environment transitions, Journal of Cleaner Production (2017), http://dx.doi.org/10.1016/j.jclepro.2017.01.027

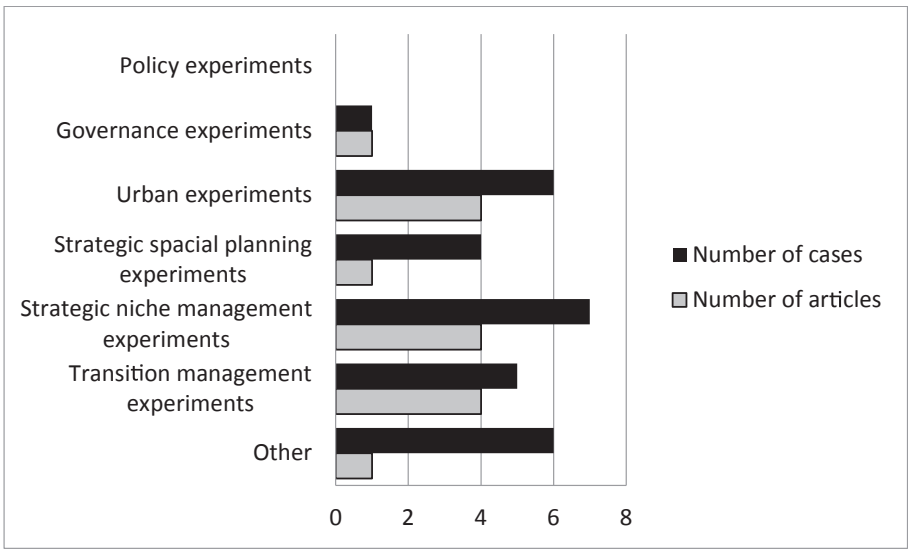

Fig. 1. Summary of the types of experiments that were mentioned in the articles.

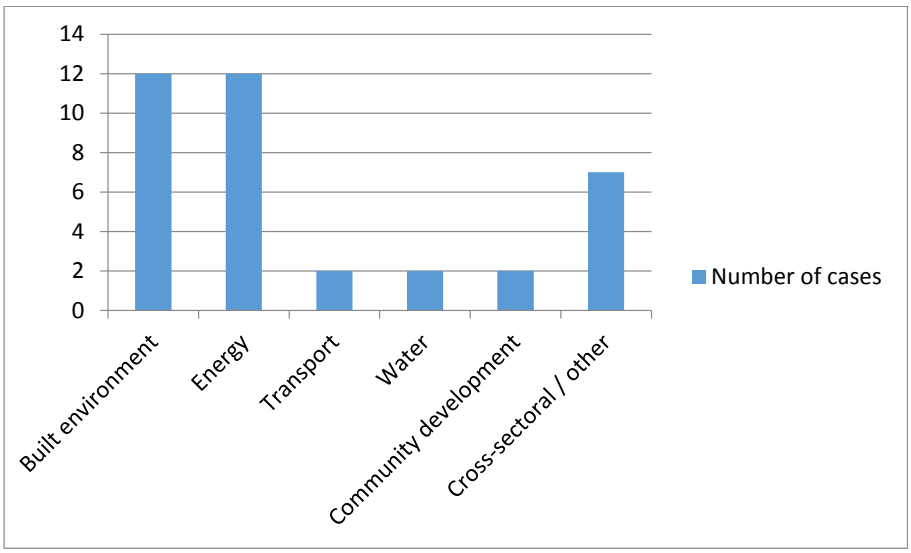

Fig. 2. Sector focus that the experiment cases portrayed.

Eighteen case studies were based in Europe (Belgium, Denmark, Netherlands, the UK, Finland, and Slovenia), six in Asia (India), two in Australia, two in Africa (South Africa) and one in South America (Brazil). Local government involvement was present in all but two cases, while the national government was involved in ten. There was a great variety in the leading actors behind the experiment, ranging from the public sector (municipalities, regional administration, and environmental ministry) to researchers, companies, entrepreneurs and independent groups. The cases analysed are summarised in Appendix 2.

Technological innovation was a topic in 11 cases, of which 10 cases included also social innovation. In total, an element of social innovation was present in most (19) experiments. While there were many similarities between the experiments, including a predominantly local or regional focus and the inclusion of elements towards social change, the experiments still presented a very wide range of processes. Their aims ranged from technology piloting and new market creation to creating sustainable visions and community engagement. In two cases, aims to experiment in low carbon were also connected to social housing objectives.

4.1. Outputs and outcomes of experiments

In evaluating the experiments the study focused on seven types of outputs and outcomes; listed in Table 2 in the order of frequency of appearance. Besides the experiments generating learning about the experimental intervention and what works, three documented outputs and outcomes strongly focused on elements of learning: changed discourse, policy and institutional change, and changed consumer or citizen practices. In addition, four other types are examples of different substantive outputs and outcomes: new technology, built environment and infrastructure change, new business practices and new markets or market change. The occurrence of a particular output or outcome was evaluated as it was described in the source article(s) and the method of investigator triangulation revealed that there was some uncertainty in whether a particular output or outcome had been achieved or not.

Reflecting the uncertainty described above, 20–27 of the

Please cite this article in press as: Kivimaa, P., et al., Experiments in climate governance – A systematic review of research on energy and built environment transitions, Journal of Cleaner Production (2017), http://dx.doi.org/10.1016/j.jclepro.2017.01.027

Table 2
Types of change that the experiments generated (n = 29).

Type of change	No. of cases observed	No. of cases with uncertain outcome	Description
Changed discourse	20	7	**Outputs:** Often described as the production of a new vision or the integration of previously detached discourses **Outcomes:** Changes in the shared visions, new narratives with a more positive tone, internalisation of new ways of thinking**;** improved cognitive understanding.
New technology	17	4	**Outputs**: Practical applications of new energy technologies, including PV, solar water heating, various other building heating systems, biogas and ceiling insulation; creation of new technological solutions for building energy efficient and passive houses and sustainable roofs; a bicycle taxi and a metering device. (The case studies did not extend to outcomes related to technology diffusion beyond the experiment phase) **Outcomes**: Wider replication of 'successful' experiments in new energy technologies.
Built environment or infrastructure change	15	4	**Outputs**: Temporary changes in land use planning with respect to energy efficient housing and town planning, station proximity to services, and water management. Building of low carbon infrastructure. Often operating at the district level as a test case. **Outcomes:** Insights into how wider changes can be achieved
Policy and institutional change	13	5	**Outputs**: Introduction of new spatial and district planning practices for enhancing eco-efficient and energy-efficient construction, renovation, transport, and water management; regionalisation of previously local policymaking; using local, outside actors in municipal or regional policymaking (often using the transition management approach), and the development of the role of the public actors. **Outcomes**: "a new political space" and "new governance rules and practices".
New business practices	12	7	**Outputs**: Introduction of novel business models for transport and renewable energy, in the latter case often combining product and service (maintenance). **Outcomes**: Changing business practices for farmers to maintain local environmental conditions; ESCO-promoted businesses based on alternative technologies and infrastructure networks; increase in new jobs as a result of the carbon neutral municipalities' network activities.
New market or market change	8	7	**Outcomes:** Emergence of markets for energy efficient social housing; maintenance and development of solar PV and biomass extraction markets.
New consumer/citizen practices	8	1	**Outputs:** Citizen engagement in local communities as operators and providers of solutions and services; alternative communities diverting from mainstream. **Outcomes:** altered energy (technology) consumption practices; energy saving as a way to reduce economic hardship.

reviewed experiments were described to have resulted in changed discourses or created new visions. A changed discourse is here understood as a general change in how issues are presented and debated. In this category, learning extended from the creation of visions within experiments (output) to more profound changes in thinking and understanding as an outcome. It is not possible to determine the disruptive force of the changed discourses as the studies tend to cover too short time periods.

13-18 experiments involved policy and institutional change, as mostly direct outputs from the experiments rather than more long-term proven outcomes. Yet, those experiments that resulted in policy and institutional change appear to have been able to affect the regime to some degree. Changed consumer or citizen practices were evident in 8 or 9 experiment descriptions.

A number of experiments had resulted in substantive changes in technology, built environment, or business in an environmentally (or climate) friendly direction. New technology, and changed built environment and infrastructure were observed in more than half of the experiments. They were also fairly unambiguous, as the proportion of uncertain observations was small. Changed business practices and market creation were also observed, but one third of the observations were uncertain, suggesting that the interpretation of outcomes is more difficult than of the (typically intended) technological outputs of experiments. Although new business models were associated with new technologies, it was often too early to tell, whether the business model would lead to market disruption.

Table 2 shows that a selected number of outcomes link to the ideas deepening (shifts in ways of thinking and practices and organising physical, economic and institutional structures), broadening (repeating experiments in different contexts and linking to other domains) and scaling up (embedding an experiment in established ways of thinking, doing and organising) (Grin et al., 2010), scaling up appearing as the least clear outcome. This does not, however, mean that they succeeded in disrupting the existing regime. The impact appears in many cases to be modest or incremental, questioning the role of experiments as a disruptive force.

While most experiments appeared to have supported the wider objectives they were expected to advance, some showed the opposite effect. Some of the 'experiments' presented a return to more traditional policy approaches (that at least the authors viewed as negative) or experienced sub-optimal solutions or non-sustainably operated technology over the course of time, particularly evident in the Indian bioenergy heating experiments that had been followed up during several years after initiation.

For many experiments, the academic analysis had occurred so

Please cite this article in press as: Kivimaa, P., et al., Experiments in climate governance – A systematic review of research on energy and built environment transitions, Journal of Cleaner Production (2017), http://dx.doi.org/10.1016/j.jclepro.2017.01.027

soon after that no definite results on the transformative effects were provided. This suggests more broadly the need for further studies what would empirically revisit these experiments after some time has elapsed. The renewable energy system experiments in India were exceptional in covering long periods of time – even over a decade (Romjin et al., 2010). Such long-term studies are important to demonstrate the fragility and evolution of experiments – in the Indian case many were halted due to intra-village conflicts over biomass resources and ownership. However, these combinations of partial 'success' and 'failures' can be important for diffusion as the lessons learned can benefit future governance interventions carried out subsequently in other locations (Romjin et al., 2010). This demonstrates the importance of learning in relation to substantive outcomes and also puts demands on the reporting; it is important to identify stumbling blocks and areas of progress.

The Parkstad Limburg transition arena in 2001 (van Buuren and Loorbach, 2009) has also led to the application of the same approach elsewhere (mainly in the Netherlands and Belgium) in several reported cases during 2007–2013 (Loorbach and Rotmans, 2010; Nevens and Roorda, 2014; Wittmayer et al., 2014), which can be subsumed under 'broadening'. The experiment to set up Carbon Neutral Municipalities Network in Finland (Heiskanen et al., 2015) has through good experiences resulted in the expansion of the network as well as an emulation of the model to a network of resource efficient municipalities. These experiments have been close to piloting or prototyping of an idea to develop practice. They have included substantial elements of action research and their ability to influence policies and wider regimes depends crucially on successful duplication and also use as iconic examples in policy development.

What becomes clear from the analysis is that rather than upscaling many of the described experiments make connections between different experiments or duplicate successful experiments (broadening) to achieve wider system transitions. This emerging network of local level experiments could enable system transition, fitting the MLP heuristic of regime change based on the emergence of a new "dominant design." At this point the experiments cease and turn into a new form of governance. However, 'successful' experiments in district-level land use planning to support more eco- and energy-efficient buildings (e.g. Holm et al., 2011) also create at least potential – if not yet realised outcomes – of systemic change based on scaling up of local planning practices through regulatory change and improved building technology with global upscaling potential.

4.2. Governance innovation in the experiments

Elements of governance innovation were detected in 12 cases. Following Upham et al. (2014), governance innovations were considered to be the first practical application, in a given country, sector or context, of either a novel process to address a concern related to mitigating or adapting to climate change or a new type of goal, strategy or an instrument (either public, private or public-private). Only Bos et al. (2013) and Bos and Brown (2012) dealt with governance innovation by explicit recognition, whereas the other case studies in the sample described governance innovations, albeit not using explicit terminology. This suggests that the role of experiments in the governance innovation for societal transitions needs to be explored further.

Innovative governance processes were in three cases associated with transition management and in two other cases linked to land use planning, including an explorative planning process for an ecological and energy efficient residential area (Holm et al., 2011) and a novel kind of collaborative process in identifying priorities and solutions for urban water planning (Bos and Brown, 2012). Innovative governance 'instruments' included a strategic spatial planning framework (Olesen and Richardson, 2012), eco- and energy requirements for new buildings within a defined district (Holm et al., 2011), a public-private energy service company ESCO and the London Plan (Bulkeley et al., 2014b), and a network of smaller municipalities as change laboratories for mitigating climate change (Heiskanen et al., 2015).

In the Transition Arena Parkstad Limburg the process innovation was based the idea that actors outside the regular administrative network could form a social vision steering the new master plan for the region (van Buuren and Loorbach, 2009). This vision also had the potential to be an innovative output. Another case of process innovation reported by van Buuren and Loorbach (2009) was a pilot project, "an experiment garden" that similarly to the transition arena approach had a core group operating outside the administrative network but with frequent contacts to the administration in drafting an environmental impact statement for the municipality and developing practical innovations. Both of these can be seen as governance experiments for (local) engagement and empowerment that do not necessarily challenge existing regimes but may generate new learning.

In Finland, the bringing together of small municipalities outside the main cities to act as "change laboratories" became a governance experiment for new solutions to climate change mitigation with co-benefits such as job creation (Heiskanen et al., 2015). This can be seen as an experiment for local engagement and empowerment within the existing regime, and an innovative way to connect local activities, support small municipalities in climate governance, and transfer lessons learned (broadening). It included process innovation through a new way to coordinate local climate activities and innovative outcome in the form of a new kind of network of municipalities expanding to new contexts.

The development of urban energy in London (Bulkeley et al., 2014b), built on the active involvement of the Mayor and the city administration in aligning institutions, techniques and artefacts around low-carbon and decentralised energy provision (process innovation), resulting in specific experiments with novel solutions such as energy service companies aiming for energy saving and production using photovoltaics (innovative outcome). The governance experiment tested new ways to set transformative economic processes in motion and could potentially lead to greater change.

Experiments that try out new ways to motivate the application of sustainable energy solutions can be interesting as innovations in governance outputs (e.g. policy instruments). For example, Stenløse Syd District Planning with Eco-requirements in Denmark focused on one district, experimenting how a set of advanced eco- and energy-requirements for new buildings within district area planning could influence the building sector and the market. By becoming a showcase for 'conventional families' of the potential in normal but sustainable dwellings (Holm et al., 2011), it could disrupt housing and housing policies in the long run. The State of Sao Paolo in Brazil experimented with introducing solar heated water systems in social housing by new contractual terms for reference and procurement, resulting in market creation for and diffusion of new technology (Bulkeley et al., 2014c). Yet another approach was to focus heavily on empowering. Municipalities

Please cite this article in press as: Kivimaa, P., et al., Experiments in climate governance – A systematic review of research on energy and built environment transitions, Journal of Cleaner Production (2017), http://dx.doi.org/10.1016/j.jclepro.2017.01.027

Table 3
A typology of experiments derived from the case study survey.

Type of experiment	Spatial scale	Setting	Sector focus	Reversibility	Key actors	Number of cases in the review
Niche creation	Initially local rural/urban but with an aim to expand	Protected niche	One or two sectors	Easy	Local, individual innovators	9–10
Market creation	Regional, national or broader	Several niches or policy	One sector	Initially relatively easy, becoming difficult when size grows	Innovators, marketers, procurement specialists, policymakers	5–6
Spatial development	Local or regional	Concrete use of space and land	Cross-sectoral	Difficult, but slow development provides opportunities for realignment	Local/regional policy makers and stakeholders	10–11
Societal problem solving and change	Local, regional or national	Policy level	Cross-sectoral	Context dependent	Policy makers, change agents and stakeholders	15

around Sydney, Australia, experimented with household-targeting series of workshops as a policy measure that led to a range of new skills for inhabitants as well as a modest new "political space" among the participating municipalities (McGuirk et al., 2015).

5. Discussion

This section briefly discusses the nature and focus of experiments (first research question), and addresses their outputs and outcomes as well as how experiments connect to low carbon and climate resilience transition (second question). It starts off by proposing a new typology on governance-related experiments connecting the range of types, scales and purposes of climate change or socially oriented experimentation.

5.1. From an overview of the review to a new typology of governance-related experiments

As shown above, the reviewed experiments cover a range of issues. Most attention has been given to renewable energy and energy efficiency improvements in housing. A few cases address adaptation, for example, through water management. The search for cases did not reveal any studies of experiments targeting the reduction of energy demand regionally or, for example, in transport. Moreover, experimentation in other pertinent areas, such as agriculture and food did not appear within the general search terms used. This may be due to agricultural policies being negotiated in detail with strong stakeholders and, thus, not amenable to experimentation (Valipour et al., 2015), although the sector in general demonstrates continued activity in terms of innovations in technology and ways of organising (Klerkx et al., 2010). Also lifestyle choices more broadly – beyond energy use and transport – were seldom subject to reported experimentation. The above indicate, first, a certain bias in the empirical topics of transitions research and, second, a focus within climate governance on certain domains, with principally technological solutions in energy production and transport, and often ignoring less technological areas and solutions.

In the literature on sustainability transitions, experiments with a strong governance, and particularly policy, dimension have not been extensively reported (Bos et al., 2013), which is confirmed by the systematic review reported here. Rather, the studies typically focus on technology experiments, e.g. in renewable energy (e.g. Romijn et al., 2010), or mixed experiments which combine technology, service and policy components, for instance in an urban context (e.g. Castan Broto and Bulkeley, 2013). This resonates with the typology emerging from this study, where (often technological) niche creation or market creation experiments are visible. Further connections could be made between *behavioural experiments* and transitions for which studies appear non-existent or at most loosely connected with the transitions debate (see Knobloch and Mercure, 2016, for a recent example).

Due to the scope of the articles, many associated with sustainability transitions, experiments were often perceived as a way to reconfigure existing socio-cultural, technological, regulative and institutional elements of socio-technical systems (e.g. Berkhout et al., 2010; Bulkeley et al., 2013, 2014b; Sengers and Raven, 2014). Their aim was to provide proofs of concept and initiate learning. The activity of the experiment itself often occurred in niche spaces protected from the mainstream environment and its "selection pressure". Many were climate governance experiments aiming to reduce greenhouse gas emissions or adapt to the effects of climate change, while some were broader in scope and focused on "real-life problems, new ways of doing things, new ways of thinking, and new ways of relating to one another and to the world" (Wittmayer et al., 2014).

Despite the shared interest in socio-technical reconfiguration, the studies gave different labels to experiments and showed different understandings of what constitutes an experiment. Thus, there was no commonly agreed terminology. Seventeen of the 25 papers reviewed did not advance or employ a specific definition of experiments. In fact their understanding of 'an experiment' had to be inferred from the cases described. In order to understand their nature it is, therefore, useful to go beyond the authors' descriptions of the experiments. Taking the different forms of experiments as a starting point, a new typology was developed (Table 3).

At one end of the spectrum, there are the experiments that aim to test a particular technology or service and create a new innovation niche around it. These fit the standard conceptualisation of transition studies and can therefore be labelled as "*niche creation experiments*". They are well defined and easily recognisable as separate experiments that have a limited duration and specific outputs. At the other end of the spectrum, experiments are oriented towards larger scale problem solving or change processes typically through joint vision creation. These "*societal problem solving or change experiments*" frequently involve an element of empowering citizens and the local community to take more ownership, either through shared arrangement with the administration or as an alternative to it, sometimes associated with novel governance or institutional arrangements. In these, the distinction between outputs and outcomes is blurred. They can also be seen to be related to 'backcasting experiments' (Davies and Doyle, 2015) where concrete activities are initiated by scenario work.

Please cite this article in press as: Kivimaa, P., et al., Experiments in climate governance – A systematic review of research on energy and built environment transitions, Journal of Cleaner Production (2017), http://dx.doi.org/10.1016/j.jclepro.2017.01.027

Intermediate types of experiments have a strategic objective to stimulate new markets or change the market conditions to favour more sustainable technologies, such as more energy efficient buildings or renewable energy technologies. The "*market creation experiments*" involve attempts to change market conditions. In one case an experiment encouraged the creation of practical examples of new buildings through consumer engagement and the expansion of an existing eco-label into the building sector.[3] In another case, the aim was merely to maximise the region's economic benefit, while it was hoped to result in some sustainability outputs, yet none were reported in the article. The fourth category that was identified, based on the cases, comprises "*spatial development experiments*" that aim towards long-term spatial development with sustainability benefits. They resemble the societal problems solving experiments, but are distinct in their focus on the spatial aspects of development.

The typology points to different governance strategies regarding experiments. For example, niche creation experiments often focus on outputs and a limited set of technologies, while market creation or societal problems solving experiments are outcome oriented and likely to be more open to the idea of technology neutrality (cf. Azar and Sanden, 2012). A proposition is made that this typology can be used in thinking about experiments in the context of climate governance as well as guide further research on experiments in a more informed way of the plurality of experimentation.

In addition to the typology, a definition of experiments can guide future work on climate governance experiments. Tassey's (2014) definition of policy experimentation can be used as a basis to define also broader governance experiments as '*deliberate field-trials of innovations that operate in a temporary space and scale, are reversible during the trial period, and are designed to challenge and disrupt status quo policies and contribute to [social] learning on how to advance decarbonisation and climate transitions*' (as opposed to 'pure' advocacy of a particular solution). The application of this definition can be guided by the proposed typology that clarifies how experiments inform and contribute to transitions.

5.2. Outcomes of experiments

It is somewhat paradoxical that experiments are assumed to be a key part of the transition management approach, while the analyses of empirical experiments and the criteria by which they are set up are still poorly defined and explored (cf. Porter et al., 2015). One reason is that TM is itself at an experimental stage, which was initiated in the Netherlands (Dietz et al., 2008; Kern and Howlett, 2009). That said, when experiments are such a key explanatory concept, transitions scholars should be much more specific about their nature, characteristics and, particularly, their expected outcomes.

As shown above, outcomes are particularly pertinent in discussing the role of experiments in transitions. Whereas the underlying intention of transition experiments is to contest the existing socio-technical configurations (Bulkeley et al., 2014b) that in previous research has been identified as key contributor to high-carbon path dependence (e.g. Unruh, 2000; Pierson, 2004) visible empirical examples of this have been rare in the covered experiments literature. Due to the limited timeframe adopted in many case studies, the connection between experiments and institutional change is often left underexplored. The fragility of experiments (Romjin et al., 2010) combined with the path dependent nature of institutions (Unruh, 2000; Pierson, 2004) suggests that experiments seldom lead to major change of governance. The interesting question, thus far underexplored in the literature, is how experiments can lead to more permanent institutional changes.

The systematic review of experiments shows that changed discourse has been the most common outcome (Table 2). This can refer to anything from profound changes that occur when problems and possible solutions are reframed (e.g. Bos et al., 2013) to, at times, purely rhetorical changes (as in the case described by Evans and Karvonen, 2014). When becoming something more than rhetoric disguise (only presented in one of the cases), this is a valuable outcome of experimentation. For example, Scrase and Ockwell (2010) have found that transitions in low-carbon energy systems demand a *reframing* of energy policy problems and solutions. This reframing in turn can act as a key entry point for governance innovation or other types of regime-level change (Upham et al., 2014). Moreover, Berkhout et al. (2010) have argued that 'social aspirations that are becoming embedded in an institutional order typically first need to engage at the macro-level of the landscape of general opinion, legislation and so on, before they can become effective in seeding transition'.

What is crucial for transitions is how the experiments expand to challenge existing unsustainable, high-carbon regimes (policies) and how broadening and upscaling happens. This review suggests that deepening is much more common that broadening, upscaling being the rarest outcome. While experiments may be politically less difficult than overturning high-carbon regimes through broad political decisions or legislation, they will remain "just" experiments with limited impact if they do not lead to learning and fail to generate commitment for future action.

Brown and Vergragt's (2008, p. 113) define three criteria for successful experiments as (1) a functioning, socially-embedded new configuration or technology or service, (2) the occurrence of higher order learning among the participants, and (3) a change in the interpretive frames or problem definitions of future users and the participants to the experiments.

Many of the reviewed experiments provided proof (output) through piloting or prototyping that the new products or services work and that they can in principle be employed on a larger scale (for example disabled mobility in Cape Town, taxi metering system in Bangkok, photovoltaics in London and low energy housing in Ljubljana). These represent success at the level of the experiment besides the shifts in thinking and practices of the actors taking part (contextual learning through broadening, following Grin et al., 2010). Finding clear evidence of higher order learning from a particular set of experiments and transforming regimes is much harder. Some indications can be obtained, if the niches that the experiments reside in have a likelihood of continued existence, even after the direct support for the experiment has ended. However, this does not mean that the broader strategic goal of low-carbon or sustainability transition would have become any closer.

It has been claimed that the critical process is the (rapid) broadening or scaling up of the experiment, resulting in a new emerging dominant (technological, social, institutional) design challenging existing regimes and, as Grin et al. (2010) argue, a new constellation of culture, practices and structure gradually attaining higher influence and stability. Only weak signs of broadening were detected in most of the reviewed experiments and the transition arenas were mostly activities driven by dedicated researchers rather than activities rapidly adopted by all planners or community developers. There is, thus, a clear need to develop a tradition of critical evaluation of experiments. Without it there is a risk that experiments become a political Potemkin village that hides the need to change policies for real transitions.

[3] The "Swan label" has so far been mainly used for consumer goods and small appliances http://www.nordic-ecolabel.org/criteria/product-groups/?p=3 [visited Nov 10, 2015].

Please cite this article in press as: Kivimaa, P., et al., Experiments in climate governance – A systematic review of research on energy and built environment transitions, Journal of Cleaner Production (2017), http://dx.doi.org/10.1016/j.jclepro.2017.01.027

5.3. Future research avenues

The pool of the reviewed experiments represent a range between niche and regime levels. However, there is generally a lack of information on the inputs, processes and configurations that climate change experiments entail, which makes it difficult to connect them to the wider literature on policy experiments (e.g. Heilmann, 2008). Therefore, there is a need for more empirical accounts that examine *governance* and *policy* experiments from a transition perspective; how the experiments link to more long-term outcomes, and what is needed beyond and after the experiments.

To generate greater insights on climate governance, fruitful areas of future research include: (1) the successes and shortcomings of climate governance experiments with reference to the articulations of policy, politics and polity – where is the inertia that experiments have to overcome in order to become 'contagious'? (2) the exploration of 'accidental experiments' or 'quasi-experiments' in governance and policy such as the differences in city level climate policy as well as the conditions under which these experimental activities emerge; and (3) long term aggregate evaluations of experiments - what happens after the experiment and how can societies reap the benefits of an 'experimental society' for sustainability transitions.

6. Conclusions

To conclude, this study finds that there is much diversity in the way that the term 'experiment' is used. This article seeks to portray a more coherent view of governance experiments in the context of climate change, whilst recognising the diversity of purposes of experimentation, and the outputs and outcomes they generate. The four identified categories (or purposes) of experiments – niche creation, market creation, societal problem solving and spatial planning – together with a new definition, can be used to guide academic enquiries and inform policy debates and their applicability should be tested in other governance contexts.

This article also reveals that different categories of experiments differ in their outputs and outcomes. Some experiments can have significant outcomes that change the discourse whereas others facilitate the emergence and diffusion of new technologies or direct changes in the built environment. Still others allow different types of governance innovation to be employed and tested, contributing to change in policy and institutions. Major societal transitions require changes that relate to governance encompassing policy, politics and polity. This suggests that regime changes towards low-carbon and climate-resilient societies require a systematic deliberate combination of different types of experiments, with each contributing slightly different aspects to the processes. The alignment to a new dominant design in the sense of the MLP is likely to require such width in experimentation.

There is a particularly urgent need to develop and conduct in-depth ex-post evaluations of experiments and clusters of experiments. Such studies can reveal unfounded hopes placed on experiments. More importantly, they can also teach us how to use experiments to highlight ways of overcoming political and institutional difficulties and barriers to low carbon transitions. Long-term research should study climate governance and policy experiments and consider their success factors and role in low-carbon or climate-resilience transitions. We would benefit from research that would revisit many of the experiments covered in this systematic review after some time has elapsed. There is also a need to be clear about what constitutes an experiment in a given context, be transparent about the purpose and parameters of experiments and the underlying interests, and be balanced in evaluating their outputs and outcomes. These are hugely important but very demanding analytical tasks, which require resources, patience and careful research designs. Otherwise, politicians and policy makers risk basing future policy interventions on unrealistic and unfounded generalisations from experiments.

Acknowledgements

We thank Visa Kivisaari for providing assistance in article coding and two anonymous reviewers of the SPRU working paper series and four journal reviewers. Previous versions were presented at a COST funded INOGOV workshop in Helsinki 12–13 March 2014 and the International Sustainability Transitions Conference in Brighton 25–29 August 2015. The work was supported by the UK EPSRC through the Centre for Innovation and Energy Demand (CIED; http://cied.ac.uk/; grant number EP/KO11790/1) and the Academy of Finland (grant numbers 286230, 259929 and 293405). The systemic review used scholarly articles as secondary data, listed in Appendix 2 that can be accessed through their publishing journals.

Appendix 1. Search string the study used for the case study review (years 2009–2014).

Source	Search term	No. of hits/relevant papers
Scopus (articles, social sciences)	"strategic experiment*"	11/2
Scopus (articles)	experiment* AND climate AND transition*	46/5
Scopus (articles)	"policy experiment*" AND climate	6/2
Scopus (articles)	experiment* AND "energy efficiency" AND transition*	11/1
Scopus (articles)	experiment* AND "renewable energy" AND transition*	6/1
Scopus (articles)	experiment* AND "mobility" AND transition*	26/4
Scopus (articles)	experiment* AND "transport" AND transition*	20/1
Scopus (articles)	"governance experiment" AND "climate policy"	0
Scopus	experiment* AND energy efficiency AND policy	18/0
Scopus	experiment* AND "low energy" AND policy	4/0
Scopus	experiment* AND "energy saving" AND policy	7/0
Scopus	experiment* AND "climate policy"	19/5
Elsewhere identified source articles	No search word	-/4

Appendix 2. Summary of the analysed experiments.

Experiment case	Source articles	Background literature	Sector & focus	Type of experiment	Techno-logical (T), social (S), policy (P) innovation	Local/national government involved	Climate objective	Country, continent	Scale
Sustainable mobility system in the suburban areas of Cape Town	Ceschin 2014	Transition studies, transition management, strategic niche management, design for sustainability	Transport	socio-technical experiment	T, S	local	no	South Africa, Africa	Local/ suburban
ICT platform for metering motorcycle taxis in Bangkok	Sengers and Raven, 2014	Transition studies, process theory	Transport	technical mobility experiment	T, S	local	no	India, Asia	Local
Transition arena Parkstad Limburg	van Buuren and Loorbach 2009; Loorbach and Rotmans 2010	Transition management, governance of innovation	Regional development	vision-forming process based on transition management	S, P	local	no	Netherlands, Europe	Regional
Pilot project (experiment garden) Gouwe Wiericke West	van Buuren and Loorbach 2009	Transition management, governance of innovation	Land use planning; water management	Experiment garden	S, P	local	no	Netherlands, Europe	Local
Community arena building Rotterdam-Carnisse	Wittmayer et al., 2014	Transition studies; transition management	built environment, community development	community arena experiment based on transition management	S	national	no	Netherlands, Europe	Local/ suburban
Finkenstein community arena building	Wittmayer et al., 2014	Transition studies; transition management	Community development	community arena experiment based on transition management	S	local	no	Netherlands, Europe	Local/ district
Urban energy networks in London ESCO	Bulkeley et al., 2014a,b,c	Transition studies, multilevel perspective, political economy	Energy, built environment	urban climate change experiment	S, P	local	yes	United Kingdom, Europe	Local
Urban energy networks in London photovoltaics	Bulkeley et al., 2014a,b,c	Transition studies, multilevel perspective, political economy	Energy, built environment	urban climate change experiment	T, S, P	both	yes	United Kingdom, Europe	Local
Social housing and low carbon transitions in Ljubljana	Castan Broto, 2012	Transition studies, multilevel perspective.	built environment, energy	low carbon energy for housing experiment	T, S	local	yes	Slovenia, Europe	Local
Oxford Road Corridor in Machester	Evans and Karvonen 2014	urban experiments	built environment	urban laboratory	T, S	local	no	United Kingdom, Europe	Local
Herfølge – Eco Labelling and Experimenting for Opening the Market to Standard Single Houses	Holm et al., 2011	Transition studies	built environment	construction and market experiment	T, S	local	yes	Denmark, Europe	Local/ village
Stenløse Syd – District Planning with Ecorequirements	Holm et al., 2011	Transition studies	built environment	planning and building experiment	T, S, P	local	yes	Denmark, Europe	Local/ district
H2-college in Herning – Passive House and Hydrogen Energy Technology	Holm et al., 2011	Transition studies	built environment	passive house experiment	T	local	yes	Denmark, Europe	Local/ university
Hallingellie – Self-grown Radical Niche and Eco-village	Holm et al., 2011	Transition studies	built environment	eco-village experiment	T, S, P	local	yes	Denmark, Europe	Local/ village
Roof transition - transition management for a firm	Loorbach and Rotmans 2010	transition management	built environment	transition arena	T, S	national	yes	Netherlands, Europe	National
Ghent as a transition	Nevens and Roorda 2014	transition management, urban transition labs	Multiple		P	local	?	Belgium, Europe	Local

(continued on next page)

(*continued*)

Experiment case	Source articles	Background literature	Sector & focus	Type of experiment	Techno-logical (T), social (S), policy (P) innovation	Local/national government involved	Climate objective	Country, continent	Scale
management case				transition management experiment					
Eastern Jutland Region: Contested Planning Rationalities in Spatial Strategy Making	Olesen and Richardson 2012	Strategic spatial planning	Built environment	strategic planning experiment		both	no	Denmark, Europe	Regional
Greater Copenhagen Area - return to top-down state planning	Olesen and Richardson 2012	Strategic spatial planning	Built environment	strategic planning experiment	P	both	yes	Denmark, Europe	Regional
Region Zealand: Towards self-regulatory spatial strategy making	Olesen and Richardson 2012	Strategic spatial planning	Built environment	strategic planning experiment		both	no	Denmark, Europe	Regional
Uttam Urja energy service initiative	Rehman et al., 2010	Transition studies, strategic niche management	Energy	sustainability experiment	S	national/both	yes	India, Asia	Regional
A producer biomass gasification system in Hosahalli	Romjin et al., 2010	Transition studies, strategic niche management	Energy	socio-techical experiment	T, S	both	no	India, Asia	Local/ village
Biogas system in Pura	Romjin et al., 2010	Transition studies, strategic niche management	Energy	socio-techical experiment	T, S	both	no	India, Asia	Local/ village
Biogas system in Mavinakere	Romjin et al., 2010	Transition studies, strategic niche management	Energy	socio-techical experiment	T, S	local	no	India, Asia	Regional
Vegetable oil system in Kaggenahali	Romjin et al., 2010	Transition studies, strategic niche management	Energy	socio-techical experiment	T, S	both	no	India, Asia	Regional
Carbon neutral municipality in Mynämäki	Heiskanen et al., 2015	Strategic niche management	Several	local experiment	P	both	yes	Finland, Europe	Local
Urban water governance experiment in Cooks river catchment	Bos and Brown, 2012; Bos et al., 2013	Transition studies, socio-ecological systems, transition management	Water	governance experiment	S, P	local	no	Australia	Regional
Sydney-based governance experiment "Treading Lightly"	McGuirk et al., 2015	Urban experiments, carbon governance	Across	institutional experiment	S, P	local	yes	Australia	Regional
Insulated ceiling retrofit in Cape Town	Bulkeley et al., 2014c	Social housing	Energy/built environment	urban experiment	T, P	local	yes	South Africa, Africa	Local
Adoption of solar water heating in social housing of Sao Paolo	Bulkeley et al., 2014c	Social housing	Energy/built environment	urban experiment	T, S, P	local	yes	Brazil, South America	Local

References

Anderson, J.E., 2006. Public policymaking: an introduction. Houghton Mifflin, Boston, pp. 1–34.

Azar, C., Sanden, B., 2012. The elusive quest for technology-neutral policies. Environ. Innovation Soc. Transitions 1, 135–139.

Berkhout, F., Verbong, G., Wieczorek, A., Raven, R., Lebel, C., Bai, X., 2010. Sustainability experiments in Asia: innovations shaping alternative development pathways? Environ. Sci. Policy 13, 261–271.

Black, J., 2005. What is regulatory innovation? In: Black, J., Dodge, M., Thatcher, M. (Eds.), Regulatory Innovation: a Comparative Analysis. Edward Elgar, Cheltenham, pp. 1–15.

Bos, J., Brown, R., 2012. Governance experimentation and factors of success in socio-technical transitions in the urban water sector. Technol. Forecast. Soc. Change 79, 1340–1353.

Bos, J., Brown, R., Farrelly, M., 2013. A design framework for creating social learning situations. Glob. Environ. Change 23, 398–412.

Brown, H.S., Vergragt, P., 2008. Bounded socio-technical experiments as agents of systemic change: the case of a zero-energy residential building. Technol. Forecast. Soc. Change 75, 107–130.

Bulkeley, H., Castan Broto, V., 2013. Government by experiment? Global cities and the governing of climate change. Transactions of the Institute of British Geographers 38 (3), 361–375.

Bulkeley, H., Castán Broto, V., Edwards, G., 2014a. An Urban Politics of Climate Change: Experimentation and the Governing of Socio-technical Transitions. Routledge, Oxon, UK.

Bulkeley, H., Castan Broto, V., Maassen, A., 2014b. Low-carbon transitions and the

reconfiguration of urban infrastructure. Urban Stud. 51, 1471–1486.
Bulkeley, H., Luque-Ayala, A., Silver, J., 2014c. Housing and the (re)configuration of energy provision in Cape Town and São Paulo: making space for a progressive urban climate politics? Polit. Geogr. 40, 25–34.
Castan Broto, V., 2012. Social housing and low carbon transitions in Ljubljana, Slovenia. Environ. Innovation Soc. Transitions 2, 82–97.
Castan Broto, V., Bulkeley, H., 2013. A survey of urban climate change experiments in 100 cities. Glob. Environ. Change 23, 92–102.
Chan, S., Van Asselt, H., Hale, T., Abbott, K., Beisheim, M., Hoffman, M., Guy, B., Höhne, N., Hsu, A., Pattberg, P., Pauw, P., Ramstein, C., Wildenberg, O., 2015. Reinvigorating international climate policy: a comprehensive framework for effective nonstate action. Glob. Policy 6 (4), 466–473.
Ceschin, F., 2014. How the design of socio-technical experiments can enable radical changes for sustainability. Int. J. Des. 8, 1–21.
Davies, A., Doyle, R., 2015. Transforming household consumption: from backcasting to homelabs experiments. Ann. Assoc. Am. Geogr. 425–436.
de Bruijne, M., van de Riet, O., de Haan, A., Koppenjan, J., 2010. Dealing with dilemma's: how can experiments contribute to a more sustainable mobility system? EJTIR 10, 274–289.
Deitchman, B., 2014. Changing the state of state-level energy programs: policy diffusion, economic stimulus, and new federalism paradigms. Strategic Plan. Energy Environ. 33, 35–61.
Dietz, F., Brouwer, H., Weterings, R., 2008. Energy transition experiments in The Netherlands. In: van den Bergh, J., Bruisma, F. (Eds.), Managing the Transition to Renewable Energy. Edward Elgar, Cheltenham.
Evans, J., Karvonen, A., 2014. Give me a laboratory and i will lower your carbon footprint!' — urban laboratories and the governance of low-carbon futures. Int. J. Urban Regional Res. 38 (2), 413–430.
Frantzeskaki, N., Loorbach, D., Meadowcroft, J., 2012. Governing societal transitions to sustainability. Int. J. Sustain. Dev. 15, 19–36.
Geels, F., 2005. Processes and patterns in transitions and system innovations: refining the co-evolutionary multi-level perspective. Technol. Forecast. Soc. Change 72, 681–696.
Geels, F., 2011. The multi-level perspective on sustainability transitions: responses to seven criticisms. Environ. Innovation Soc. Transitions 1, 24–40.
Government Programme, 2015. Valtioneuvosto. Accessed November 6, 2015. http://valtioneuvosto.fi/en/sipila/government-programme.
Grin, J., Rotmans, J., Schot, J., 2010. Transitions to Sustainable Development. Routledge, New York.
Heilmann, S., 2008. Policy Experimentation in China's Economic Rise. Springer Science.
Heiskanen, E., Jalas, M., Rinkinen, J., Tainio, P., 2015. The local community as a "low-carbon lab": promises and perils. Environ. innovation Soc. Transitions 14, 149–164.
Hildén, M., 2014. Evaluation, assessment, and policy innovation: exploring the links in relation to emissions trading. Environ. Polit. 23 (5), 839–859.
Hoffman, M.J., 2011. Climate Governance at the Crossroads: Experimenting with a Global Response. Oxford University Press, New York.
Holm, J., Stauning, I., Sondergård, B., 2011. Local climate mitigation and eco-efforts in housing and construction as transition places. Environ. Policy Gov. 21, 183–198.
Hoogma, R., Kemp, R., Schot, J., Truffer, B., 2002. Experimenting for Sustainable Transport: the Approach of Strategic Niche Management. Spon Press, London.
Jordan, A., Huitema, D., 2014. Innovations in climate policy: the politics of invention, diffusion, and evaluation. Environ. Polit. 23 (5), 715–734.
Jordan, A., Huitema, D., Hilden, M., van Asselt, H., Rayner, T., Schoenefeld, J., Tosun, J., Forster, J., Boasson, E., 2015. Emergence of polycentric climate governance and its future prospects. Nat. Clim. Change 5, 977–982.
Kemp, R., Loorbach, D., Rotmans, J., 2007. Transition management as a model for managing processes of co-evolution towards sustainable development. Int. J. Sustain. Dev. World Ecol. 14, 78–91.
Kern, F., Howlett, M., 2009. Implementing transition management as policy reforms: a case study of the Dutch energy sector. Policy Sci. 42, 391–408.
Klerkx, L., Aarts, N., Leeuwis, C., 2010. Adaptive management in agricultural innovation systems: the interactions between innovation networks and their environment. Agric. Syst. 103, 390–400.
Knobloch, F., Mercure, J.-F., 2016. The behavioural aspect of green technology investments: a general positive model in the context of heterogeneous agents. Environ. Innovation Soc. Transitions 21, 39–55.
Kohler-Koch, B., 1999. The Evolution and Transformation of European Governance. In: Kohler-Koch, B., Eising, R. (Eds.), The Transformation of Governance in the European Union. Routledge, London, New York, pp. 14–35.
Kooiman, J., 2003. Governing as Governance. Sage, London.
Lange, P., Driessen, P., Sauer, A., Bornemann, B., Burger, P., 2013. Governing Towards Sustainability—Conceptualizing Modes of Governance. J. Environ. Pol. Plan. 15 (3), 403–425. http://dx.doi.org/10.1080/1523908X.2013.769414.
Loorbach, D., Rotmans, J., 2010. The practice of transition management: examples and lessons from four distinct cases. Futures 42, 237–246.
Lucas, W., 1974. The Case Survey Method: Aggregating Case Experience. The Rand Corporation, Santa Monica.
Markard, J., Raven, R., Truffer, B., 2012. Sustainability transitions: an emerging field of research and its prospects. Res. Policy 41, 955–967.
McFadgen, B., Huitema, D., 2017. Experimentation and Learning. The Design of Policy Experiments and Their Learning Effects, a Conceptual Framework and Application to a Case Study from the Netherlands (unpublished).
McGuirk, P., Dowling, R., Brennan, C., Bulkeley, H., 2015. Urban carbon governance experiments: the role of australian local governments. Geogr. Res. 53, 39–52.
Nair, S., Howlett, M., 2015. Scaling up of policy experiments and pilots: a qualitative comparative analysis and lessons for the water sector. Water Resour. Manag. 29 (14), 4945–4961.
Nevens, F., Roorda, C., 2014. A climate of change: a transition approach for climate neutrality in the city of Ghent (Belgium). Sustain. Cities Soc. 10, 112–121.
Newig, J., Fritsch, O., 2009. The Case Survey Methods and Applications in Political Science. APSA 2009 Toronto Meeting Paper. Available at SSRN: http://ssrn.com/abstract=1451643.
Onwuegbuzie, A., Leech, N., Collins, K., 2012. Qualitative analysis techniques for the review of the literature. Qual. Rep. 17, 1–28.
Olesen, K., Richardson, T., 2012. Strategic planning in transition: contested rationalities and spatial logics in twenty-first century Danish planning experiments. Eur. Plan. Stud. 20, 1689–1703.
Petticrew, M., Roberts, H., 2006. Systematic Reviews in the Social Sciences: a Practical Guide. Wiley-Blackwell.
Pierson, P., 2004. Politics in Time: History, Institutions and Social Analysis. Princeton University Press, Princeton.
Porter, N., Claassen, M., Timmermans, J., 2015. Transition experiments in amsterdam: conceptual and empirical analysis of two transition experiments in the WATERgraafsmeer program. Technol. Forecast. Soc. Change 90, 525–537.
Rehman, I., Kar, A., Raven, R., Singh, D., Tiwari, J., Jha, R., Sinha, P., Mirza, A., 2010. Rural energy transitions in developing countries: a case of the Uttam Urja initiative in India. Environ. Sci. Policy 13 (4), 303–311.
Romjin, H., Raven, R., de Visser, I., 2010. Biomass energy experiments in rural India: insights from learning-based development approaches and lessons for Strategic Niche Management. Environ. Sci. Policy 13, 326–338.
Sabel, C., Zeitlin, J., 2012. Experimentalist governance. In: Levi-Faur, D. (Ed.), The Oxford Handbook of Governance. Oxford University Press, Oxford, pp. 169–186.
Sanderson, I., 2002. Evaluation, policy learning and evidence-based policy making. Public Adm. 80 (1), 1–22.
Schot, J., Geels, F., 2008. Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. Technol. Anal. Strategic Manag. 20 (5), 537–554.
Scrase, J.I., Ockwell, D.G., 2010. The role of discourse and linguistic framing effects in sustaining high carbon energy policy e an accessible introduction. Energy Policy 38, 2225–2233.
Sengers, F., Raven, R., 2014. Metering motorbike mobility: informal transport in transition? Technol. Anal. Strategic Manag. 26, 453–468.
Smith, A., 2006. Niche-based approaches to sustainable development: radical activists versus strategic managers. In: Voss, J.-P., Bauchnecht, D., Kemp, R. (Eds.), Reflexive Governance for Sustainable Development. Edward Elgar, Cheltenham.
Stewart, F., 2012. Transformative innovation policy to meet the challenge of climate change: sociotechnical networks aligned with consumption and end-use as new transition arena for a low-carbon society or green economy. Technol. Anal. Strategic Manag. 24, 331–343.
Tassey, G., 2014. Innovation in innovation policy management: the experimental technology incentives program and the policy experiment. Sci. Public Policy 41, 419–424.
Unruh, G.C., 2000. Understanding carbon lock-in. Energy Policy 28, 817–830.
Upham, P., Kivimaa, P., Mickwitz, P., Åstrand, K., 2014. Climate policy innovation: a socio-technical transitions perspective. Environ. Polit. 23, 774–794.
van Buuren, A., Loorbach, D., 2009. Policy innovation in isolation? Public Manag. Rev. 11, 375–392.
Valipour, M., Ahmadi, M., Raieni-Sarjaz, M., et al., 2015. Agricultural water management in the world during past half century. Arch. Agron. Soil Sci. 61, 5.
Vedung, E., 1997. Public Policy and Program Evaluation. Transaction Publishers, New Brunswick.
Verbong, G., Christiaens, W., Raven, R., Balkema, A., 2010. Strategic Niche management in an unstable regime: biomass gasification in India. Environ. Sci. Policy 13, 272–281.
Voss, J.-P., Smith, A., Grin, J., 2009. Designing long-term policy: rethinking transition management. Policy Sci. 42, 275–302.
Voytenko, J., McCormick, K., Evans, J., Schliwa, G., 2016. Urban living labs for sustainability and low carbon cities in Europe: towards a research agenda. J. Clean. Prod. 123, 45–54.
Wittmayer, J., Schäpke, N., van Steenbergen, F., Omann, I., 2014. Making sense of sustainability transitions locally: how action research contributes to addressing societal challenges. Crit. Policy Stud. 8, 465–485.

Please cite this article in press as: Kivimaa, P., et al., Experiments in climate governance – A systematic review of research on energy and built environment transitions, Journal of Cleaner Production (2017), http://dx.doi.org/10.1016/j.jclepro.2017.01.027