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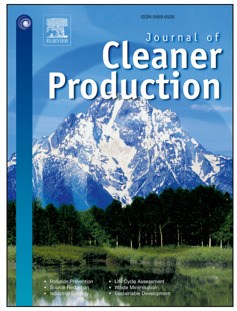

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Learning through Evaluation – A Tentative Evaluative Scheme for Sustainability Transition Experiments

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Abstract

Transitions towards sustainability are urgently needed to address the interconnected challenges of economic development, ecological integrity, and social justice, from local to global scales. Around the world, collaborative science-society initiatives are forming to conduct experiments in support of sustainability transitions. Such experiments, if carefully designed, provide significant learning opportunities for making progress on transition efforts. Yet, there is no broadly applicable evaluative scheme available to capture this critical information across a large number of cases, and to guide the design of transition experiments. To address this gap, the article develops such a scheme, in a tentative form, drawing on evaluative research and sustainability transitions scholarship, alongside insights from empirical cases. We critically discuss the scheme's key features of being generic, comprehensive, operational, and formative. Furthermore, we invite scholars and practitioners to apply, reflect and further develop the proposed tentative scheme – making evaluation and experiments objects of learning.

1. Introduction

Sustainability problems of economic development, ecological integrity, and social justice jeopardize human and social wellbeing around the world (Parris and Kates, 2003; Steffen et al., 2015). Considering the extent of the problems, viable solutions need to yield *transformational* changes, i.e., large-scale transitions of priorities, practices, and infrastructures (McAlpine et al., 2015; McCormick et al., 2013; Westley et al., 2011).

Around the world, collaborative initiatives have emerged that design, implement, and monitor experiments in real-world settings in support of sustainability transitions (Evans and Karvonen, 2011; Trencher et al., 2014a; van den Bosch, 2010). Such experiments differ with regard to their actor constellation, topical focus and governance structure (e.g. Castán Broto and Bulkeley, 2013; Voytenko et al. 2015). While in the past a large number of experiments have been led by citizens and local government organizations, a specific type of transition experiment has emerged during the last decade. The new type of transition experiment is characterized by cross-organizational collaboration between actors from academia and society (government, industry and citizenry) with the aim of collaboratively fostering transformational change and progress towards greater sustainability (Nevens et al., 2013; Voytenko et al., 2015). Although often framed differently, such initiatives can be understood to jointly experiment with a range of sustainability solutions, including but not limited to food production (e.g. Victorian Eco Innovation Lab, Australia), energy consumption (e.g. Campus as a Living Laboratory, Canada), urban living (e.g. Low Carbon Labs, Lund) and mobility (e.g. Delft Design Labs, the Netherlands). Transition experiments are essential to the scientific field of sustainability transitions (Caniglia et al., this issue) and are often carried out by real-world laboratories or labs, in contrast to isolated scientific laboratories, including but not limited to living labs, transition labs, and social innovation labs (e.g. Frantzeskaki et al., 2014; Westley et al., 2014; McCormick and Kiss, 2015, cf. supplementary material A). Thus, a given real-world laboratory can conduct various sustainability transition experiments for testing transformational changes. While different labels are used for describing this process, they all provide "spaces that facilitate explicit experimentation and learning based on participation and user involvement" (Voytenko et al., 2015, p. 4). Accordingly, sustainability transition experiments function also as an umbrella term for transformational interventions as they build on existing efforts, create new actions and add orientation to transitions. They follow a transdisciplinary research approach, integrating various actors into the experimentation process for reconciling diverging preferences and practices, as well as create ownership for sustainability problems and solutions (Lang et al. 2012). Importantly, the sustainability practices experimented on do not concern mere modification or "tinkering" of elements already present. Instead, they are radically different from the status quo, in both process and outcomes (Bernstein et al., 2014; Davies and Doyle, 2015; Evans and Karvonen, 2014).

Sustainability transition experiments often focus on defined small-scale settings, specific to a particular location and socio-cultural context (Evans and Karvonen, 2014; Voytenko et al., 2015). Following the notion of experimentation, the intention is to create positive outcomes that are replicable, transferable, and scalable to society at large (Bernstein et al., 2014; Bos et al., 2015;; Ryan, 2013). Experiments focus, for example, on socio-technical innovations (e.g. in the energy or food sector) (e.g. van der Laak et al., 2007), on networks (e.g. political and technical coalitions) (e.g. Bos et al., 2015), or on small spatial or organizational units (e.g. a neighborhood or a building) (e.g. Brown and Vergragt, 2008). In addition to having real-world impacts, such experiments are *research* endeavors to the extent that they produce *evidence* regarding both the persistent unsustainability of dominant regimes and the possible solutions to given sustainability problems within the bounded space of a laboratory (Evans and Karvonen, 2011; Wiek et al., 2015). Thus, this article posits that sustainability experiments (i) define a baseline and a goal for their evaluation, (ii) create a specific set-up to administer interventions, (iii) measure the effects of interventions against the baseline and the goal, (iv) evaluate the effects against sustainability criteria, and (v) offer evidence-supported recommendations on how to mainstream solutions (Karvonen and van Heur, 2014; Laakso and Lettenmeier, 2015; Wiek et al., 2015).

Transitions scholarship has long recognized the significant potential of transition experiments in generating new knowledge and promoting social learning (e.g. Bos et al., 2013; Farrelly and Brown, 2011; Pahl-Wostl, 2007). Iterative and reflexive monitoring and evaluation needs to be an integral part of sustainability transition experiments to support individual and organizational *learning* promoting ongoing change and up-scaling impact (Forrest and Wiek, 2014; Taanman, 2014; van Mierlo et al. 2010). By addressing the broader systemic transition context within which such initiatives sit, the opportunities for deepening, broadening, and scaling-up of such experiments could be increased (Raven et al., 2010). While the framing of actions, projects, and initiatives as experiments has become popular around the world and they are being positioned as drivers of wider transition their impacts are poorly understood (Caniglia et al., this issue). Therefore, scholars are calling for greater cross-case learning from different sustainability transition experiments (Forrest and Wiek, 2015; McCormick et al., 2013; Raven et al., 2011). Undertaking evaluative research supports conclusions regarding the success of particular interventions, aids generalizing insights, and enables the improved design and operation of experiments, helping them to become more effective and efficient (Wiek et al., 2015).

Evaluation of sustainability transition experiments is faced with various challenges. Transitions initiatives are no longer conducting ‘projects’ but aim to create a new setting for transforming conventional practices and informal power structures (Nevens et al., 2013; Kemp 1998; Geels and Ravens, 2006). Nevertheless, sustainability transition experiments often remain the most tangible approach (Nevens et al., 2013). Their objective is to initiate and facilitate radical long-term transitions (Rotmans and Loorbach, 2009; Loorbach, 2010), but orchestrate this through specific experiments, which aim to challenge the status quo. Scholars argue that aligning experimentation alongside prevalent structures and paradigms is necessary in the short-term, while ultimately aiming towards a long-term transformation (Schot and Geels, 2008; Robinson et al. 2011).

Reflexive evaluation of experiment enables learning-by-doing; a critical mechanism supporting sustainability transitions (Taanman, 2014). Thus, evaluation emerges as a core activity in transitions, periodically informing experiments to adapt, extend and revise the envisioned pathway. To achieve this requires: ex-ante evaluation prior to the implementation of experiments to inform their design; formative evaluation to adjust and improve ongoing experiments; and, ex-post evaluation to appraise the contribution of experiments to sustainability after completion. Evaluations scrutinize assumptions, structures, and values as well as related and unrelated changes in society in order to inform future actions (Schot and Geels, 2008; Rotmans and Loorbach, 2010; Robinson 2003). Embedded within these different modes of evaluation are reflexive learning processes which continually assess the transformational potential of experiments and the evaluation itself. As sustainability transition experiments are embedded within structures and power relations, advanced reflexivity within an evaluation is required (Avelino and Rotmans, 2009).

A number of studies have explored ways to appraise the outcomes of transition experiments, but coordinating efforts are widely lacking (Bai et al., 2010; Ferguson et al., 2013; Forrest and Wiek, 2014; Hart et al., 2015; König, 2015; Loorbach et al., 2015; Moloney and Horne, 2015; Moore et al., 2014; Seyfang and Longhurst 2016; Taanman, 2014; Trencher et al., 2014b). Although these studies provide useful insights into aspects of sustainability transition experiments, none of them comprehensively covers a broad array of aspects critical to (different types of) experiments. This partly arises from the diversity of the different types of initiatives surveyed, which extend from, for example, transition policy programs, transition management projects, technical innovation projects, to community initiatives or social innovation processes. In addition, learning and coordination across various transition experiments is constrained by the use of different, case-specific evaluative schemes, if one exists at all.

Other fields, such as international development and resource management, have demonstrated how evaluative schemes, if used jointly, can successfully facilitate and accelerate learning and progress, as they allow learning and coordination across similar case studies (Banerjee et al., 2010; Ostrom, 2009). For instance, the diagnostic social-ecological systems framework for analyzing elements and their interrelation in coupled social-ecological system is a pivotal example of such efforts. The framework – developed and advanced by Elinor Ostrom and others (e.g. Ostrom, 2007; Ostrom and Cox, 2010; McGinnis and Ostrom, 2014; Leslie et al., 2015; Vogt et al., 2015) – departs from conditions in common-pool resource systems that are considered crucial for enabling self-organization. While the framework provides a common terminology for understanding socio-ecological systems, without implying causal relations, it is sensitive to context specifics and supports generalization and theory building (Partelow, 2015). This facilitates interdisciplinary collaborations and invites different theories for explaining observed dynamics (McGinnis and Ostrom, 2014). The framework is widely used in research on water, food, and forestry systems (e.g. Vogt et al., 2015; Partelow and Boda, 2015; Marshall, 2015).

In this article, we present a tentative evaluative scheme for sustainability transition experiments, with the notion that when applied, this would facilitate learning across different transition experiments, and help fostering sustainability transitions. We aim to systematically support designing and improving transition experiments as well as tracing their influence on learning and transformational efforts while ensuring reflexivity regarding the limitation of such undertakings. Overall, this paper seeks to identify the essential characteristics of a tentative evaluative scheme which will increase its: broad applicability; readiness to be applied; comprehensiveness; and, its capacity to improve the performance of experiments.

The purpose of this article is to provide a conceptual basis for further discussions on the potentials, needs, restrictions, and drawbacks of experiments evaluation efforts. This applies to academic work on evaluation such as the publication of findings from various sustainability transition experiments. It also applies to practical work such as the collaborative application of the scheme involving researchers and practitioners to facilitate mutual learning. We emphasize the tentative nature of the evaluative scheme inviting participants of experiments – both in research and practice – to critically reflect upon its potentials and limitations and take part in learning from and improving transition efforts. This involves continuous changes in the evaluative features and processes of evaluation (see McGinnis and Ostrom, 2014).

This article departs from an evaluative scheme developed in a study on urban sustainability experiments (Wiek et al., 2015). Here, we further develop and expand on this study, drawing on the existing literature that deals more generally with transition experiments and initiatives. With support from this literature, the evaluative scheme ought to be:

(i) *Generic*, i.e., applicable to different types of sustainability transition experiments;

(ii) *Comprehensive*, i.e., capturing the ultimate outcomes as well as the intermediate and mediating attributes (inputs, processes, outputs) of experiments;

(iii) *Operational*, i.e., ready to be applied (including guidance on how to specify it for application to particular cases and contexts); and,

(iv) *Formative*, i.e., support experiments in becoming more effective and efficient.

The method of this article is as follows. After developing the conceptual framework for the evaluative scheme, a literature review was conducted. This drew on an array of reported sustainability experiments to illustrate and define the evaluation schemes' various dimensions. This process followed a four-step procedure. First, we identified and pooled suitable publications on experiments from Scopus and Google Scholar (see supplementary material A). The search was limited to peer-reviewed case studies to ensure some degree of scientific rigor and quality control in the analyzed material. Selection criteria were that the articles (i) were empirical studies, that (ii) reported on collaborative science-society initiatives, (iii) explicitly focused on sustainability, and (iv) employed transition approaches with an experimental character. Selected studies range from intervention studies in which the authors present their own experiments (e.g. Bernstein, et al., 2013) to case studies in which the authors report on an experiment (e.g. Evans and Karvonen, 2014). Since our literature review includes only peer-reviewed articles in English and overlooks non-refereed publications, we are cognizant of particular biases created; from excluding certain types of studies (i.e. non-refereed or non-English). Yet we consider it sufficient for the purpose of developing a tentative evaluative scheme as the reviewed literature reports on a broad range of initiatives, including possible contestation and further enrichment of the literature used in following sections. Second, we extracted information from 61 unique case studies for conceptualizing inputs, processes, outputs, and outcomes as basic categories of the evaluation scheme. Third, we identified features and related definitions, exemplified typical indicators, illustrated examples, and presented literature in support of each of the above categories. In the spirit of a *tentative* scheme, the collection of examples and indicators is not exhaustive. The presented examples of the developed features are selected according to their respective suitability intending to support operationalization of the scheme and experimental designs. The indicators, although not fully operationalized, serve as reminders and placeholders to identify and translate features into measurable parameters when operationalizing the scheme. Fourth and finally, in the process of finalizing the evaluation scheme, preliminary versions have been presented, discussed and revised according to in-depth feedback from audiences at numerous international conferences (see Acknowledgements). The input enabled initial appraisal of the scheme's applicability and comprehensiveness as well as supported deliberation regarding its use in cross-case analysis.

The article is structured as follows. In Section 2, we present the conceptual framework, followed by the evaluative scheme in Section 3. We then conclude by critically reflecting on the evaluative scheme against the four guidelines presented above.

2. Conceptual Framework for the Evaluation Scheme

The evaluative scheme presented below (Figure 1; Section 3) is used to appraise the extent to which a sustainability transition experiment generates desired effects, and how this was accomplished (i.e., through what kind of interventions). The scheme is based on the basic logic model of evaluation (McLaughlin and Jordan, 2010; Rossi et al., 2004), which is organized according to four evaluative dimensions: *inputs* that are invested into the experiment, *processes* that are performed by the experiment, *outputs* that are generated by the experiment, and sustainability *outcomes* that are accomplished by the experiment. However, there are two important modifications. First, we change the sequence of items from the *experiment* rationale (Inputs → Processes → Outputs → Outcomes) to the *evaluation* rationale with the primary interest in outputs and outcomes, and from there tracking back processes and inputs (Forrest and Wiek, 2014). Second, we depict the logical model components as parallel and interdependent, which requires iterative evaluation among the four dimensions. In other words, inputs are not only needed for initiating an experiment nor are outputs only produced after completion of a project. For example, outputs might initiate new processes or generate new investments of additional resources amid the experimentation. Thus, the presented scheme aims at being capable of capturing complex dynamic processes with overlapping and parallel interferences. The evaluation scheme is guided by the following four questions:

1. *What was generated?* – Identify the produced *outputs* and related features including direct results of the interventions; namely built capacities (results of learning processes), actionable knowledge, accountability, structural changes, up-

take of experiments, as well as generalizable insights with regards to specific issues or methods.

2. *What was accomplished?* – Identify achieved *outcomes* in terms of sustainability. This explores the extent to which generated changes support progress towards sustainability, namely socio-ecological integrity, livelihood sufficiency and opportunities, intra- and intergenerational equity, resource maintenance and efficiency, socio-ecological stewardship and democratic governance, as well as precaution and adaptation (Gibson, 2006).
3. *How was it completed?* – Identify what *processes* led to outputs and outcomes such as sequence of actions, sound methodology, collaboration, reflexivity and learning, and transparency.
4. *What was invested?* – Identify *inputs* that enabled actions and processes and related features, i.e. initial awareness, commitment, expertise, trust, and support (incl. financial and human resources).

These guiding questions can inform all types of evaluation: *ex-ante* evaluation to inform the design of experiments, *formative* evaluation to adjust and improve experiments, or *ex-post* evaluation to appraises the contribution of experiments to sustainability.

[--- Insert here Figure 1 ---]

[--- Insert here the legend of Figure 1 ---]

Figure 1: Dimensions of the evaluative scheme for appraising sustainability transition experiments.

3. Evaluative Scheme for Sustainability Transition Experiments

This section further describes the four evaluative dimensions (outputs, outcomes, processes, and inputs) and presents for each identified feature definitions, typical indicators, illustrative examples, and evaluative questions. We present instructive definitions of each evaluative feature as well as formative evaluative questions in Box 1.

3.1 Output Features

Outputs are *direct* results of sustainability transition experiments, including built capacities, actionable knowledge, structural changes, as well as the up-take of experiments (Wiek et al., 2015). These key outputs may have differing importance depending on the experiment and can be interconnected in various ways. For example the capacities built in participants enable them to generate actionable knowledge and increase accountability for the realized structural changes. Additional features include the generalization of evidence for generating outputs to support the up-take of the experiment to broader application, as well as the integration of generalizable knowledge into the scientific discourse

3.1.1 Built capacities

Sustainability transition experiments build capacities such as skills, abilities, and crafts that foster or embrace sustainability (Bos et al., 2013; Loorbach et al., 2015; Wiek and Kay, 2015). Such capacities go beyond skillfully conversing on sustainability issues towards enabling people to *act sustainably* in their everyday decision-making and practices. Built capacities include strategic competence in developing effective interventions (Schreuer et al., 2010), practical skills, such as creating and maintaining a community garden (Bernstein et al., 2014), and interpersonal competence for building coalitions and alliances (Frantzeskaki et al., 2014; Wittmayer et al., 2014). Experiments can also be used as learning settings for educating students (Bernstein et al., 2014; Ryan, 2013; Trencher et al., 2016) as well as for educating practitioners on new solutions and (possibly) new roles and responsibilities for sustainability transitions (Farrelly and Brown, 2011). Typical indicators for built capacities are post-experiment activities and practices carried out by participants that have the potential to address the given sustainability problem such as community gardening and food distribution systems, consumption of organic food products, launching of new sustainability-based businesses, expansion of networks, and incorporation of sustainability into decision-making in the public or private sector.

An illustrative example of built capacity as output of a transition experiment is the capacity built in planners and other participants to develop long-term sustainability plans in Phoenix, United States, as reported by Wiek and Kay (2015).

The evaluative question for this feature is: *Does the transition experiment build capacities in participants to generate sustainability solutions?*

3.1.2 Actionable knowledge

Actionable knowledge is evidence-supported guidance for practical application that has been tested in successful efforts to solving (or at least mitigating) a sustainability problem within the defined experimental setting (Forrest and Wiek, 2014; Frantzeskaki and Kabisch, 2016). Three knowledge types are relevant to sustainability transition experiments. The first two are analytical-descriptive knowledge about the given sustainability problem (Wittmayer et al., 2014) and anticipatory, normative knowledge about the sustainability goals (Davies et al., 2012; Frantzeskaki and Tefrati, 2016). The third knowledge output of experiments is transformational knowledge on the most effective means of fostering transitions from the current to a (more) sustainable state (Ceschin, 2014; Wittmayer et al., 2014; Bos and Brown, 2012). This feature includes scientific output as well as knowledge generated by practitioners Typical indicators for actionable knowledge may include scientific output as well as context specific transition pathways that identify strategic actions for implementing transformational change and building agreement on the problem framing.

An illustrative example of actionable knowledge as output of a transition experiment is the developed transition management approach for coordinating ambitious strategies for the City of Aberdeen, UK, as reported by Frantzeskaki and Tefrati (2016). Civil servants from the city department and participants from civil society valorized the knowledge gained in implementing experimental settings for opening a center for developing skills that are required for a low-carbon economy.

The evaluative question for this feature is: *Does the transition experiment generate actionable knowledge that provides evidence on how to generate sustainability solutions?*

3.1.3 Accountability

Accountability refers to participants' commitment, maybe even formalized through agreements and agreed-upon sanctions, to implement results generated by the experiment and dedication to positive change (Wiek and Kay, 2015). Participants develop confidence about being able to implement the selected actions when actively participating in the experiments. Participants' commitment to the identified actions is enhanced as the participants learn about the actions' effectiveness in the process of pursuing sustainability transitions. Confidence and commitment can be built especially well through transition experiments that try novel practices and experience positive results (Wittmayer et al., 2014). Allowing for ownership of the vision and promoting transition experiments as the stepping-stones for realizing sustainability goals support accountability (Frantzeskaki et al., 2014). Typical indicators for accountability are the participants' attitudes, but also more formalized commitments towards the implementation of the results.

An illustrative example of accountability as output of a transition experiment is the community center that was reopened by active citizens in Rotterdam (neighborhood of Carnisse), the Netherlands as reported by Wittmayer and Schäpke (2014). The center continued operation based on the positive results of the experiment.

The evaluative question for this feature is: *Does the transition experiment build confidence and commitment for generating and realizing sustainability solutions?*

3.1.4 Structural changes

Sustainability transition experiments generate an array of structural changes to foster rapid transformations (Evans and Karvonen, 2011; Trencher et al., 2014b). Such outputs of experiments can be subdivided into physical change (transformation of infrastructure), and societal change (transformation of institutions).

Changes in physical structures

Change of physical structures refers to the creation of new or transformation of existing buildings, infrastructures, technologies and products. These real-world changes are often radically different from the existing structures (Vergragt and Brown, 2007) and can include sustainable buildings (Trencher et al., 2014a; Vergragt and Brown, 2012), green infrastructure (Bernstein et al., 2014), innovative energy systems (Hart et al., 2015), and new vehicles (Brown et al., 2003). However, real-world changes in physical structures may also correspond to changed understandings, priorities, practices, and behavior (see below). Typical indicators for physical transformation would incorporate modified or newly built forms such as new bicycle lanes, rooftops, novel or improved products arising from new scientific knowledge and innovations. Other indicators would be commercialization of patents; shifts in the design, production and manufacturing of goods; and changes in the natural environment, for example, afforested areas or increasing green spaces in urban areas.

An illustrative example of physical changes as output of a transition experiment is the bicycle-based transport technology for elderly people that changed mobility behavior in Cape Town, South Africa reported by Ceschin (2014).

The evaluative question for this feature is: *Does the transition experiment generate physical changes that support solutions for the identified sustainability problem?*

Changes in societal realms

Sustainability experiments are also undertaken to deliver societal change. Societal change refers to the creation of new or transformation of existing networks and organizations, values and norms, rules and policies, decision-making processes, behavior and practices, and discourses, often radically different from existing ones (Bos and Brown, 2012; Davies and Doyle, 2015; Schreuer et al., 2010). Societal changes induced by experiments include changed norms (Davies et al., 2015), policies (Loorbach and Rotmans, 2010), mobility practices (Ceschin 2014), and political discourses (Loorbach and Rotmans, 2010). Typical indicators for societal change are new or altered activities, practices, routines, as well as social relations and partnerships.

An illustrative example of societal real-world changes as output of a transition experiment is the organizational innovation in health care in the Netherlands reported by Loorbach and Rotmans (2010). Contrary to conventional practices, the “Buurtzorg” (District Care) establishes small nurse teams that are responsible for a small group of clients, have their own budget and possess freedom to self-organize their professional practices.

The evaluative question for this feature is: *Does the transition experiment generate societal changes that support solutions for the identified sustainability problem?*

3.1.5 Facilitate up-take

The ultimate objective of conducting transition experiments is to provide generalizable evidence that a solution works beyond overly specific and narrow circumstances (Bos and Brown, 2012; Vandevyvere and Nevens, 2015). A transition experiment is intended to facilitate the up-take of its results. This anticipates that the results of an experiment can be either transferred or scaled for broader use. This allows the participants and affected stakeholders to utilize the results of the experiment for formulating solutions to similar challenges, either in other contextual settings (transferability) or in system wide applications (scalability) (Ceschin, 2014). More specifically, transferability refers to the potential that the experiment can be replicated – whether application of the experiment in a different context would generate similar results. Scalability refers to the potential that the experiment can be expanded - whether nurturing the experiment in the given context would generate desired results throughout the system. This can be achieved through 'scaling out' which refers to repeating the experiment in the same context or through 'scaling up' which refers to integrating and applying the experiment at a higher system level. Facilitating the take-up requires generalizing insights gained through the experimentation including the anticipation of potential negative side effects. Furthermore, experiments allow for additional insights that can enrich the scientific discourse, including substantiation of methods for or theories of socio-ecological transformations.

Transferability

Transferability refers to generalized lessons learned from an experiment that can be applied in different contexts (Ceschin, 2014). This requires extraction of generic, process-related factors and case specific knowledge that have supported application (Brown and Vergragt, 2008; Forrest and Wiek, 2015; Westley et al., 2014). Indications of transferability can best be generated through feasibility and comparative studies. It should be noted that replicating the experiment in similar or different contexts (e.g. Ray, 2013) is *actually transferring* the insights and thus goes beyond the indication of transferability. Exemplary insights for transferability can be gained through related feasibility studies, comparative studies, or contextualization of an experiment through conceptual reasoning. Related typical indicators are reliability of insights in other contexts or validity of cause and effect assumptions in various settings.

An illustrative example of transferability as output of a transition experiment is reported by Bos and Brown (2012). Following the implementation of an experiment in a catchment area in Sydney, Australia, a project was initiated to transfer and extend sustainable water management planning into other areas.

The evaluative question for this feature is: *Does the transition experiment indicate how the sustainability solution can be transferred to different contexts?*

Scalability

Scalability refers to generalizable knowledge that facilitates the up-take of experiment results. This can concern system-wide applications through "scaling out" in the initial system, or applications at a larger system level through "scaling up" (Bos and Brown, 2012; Ceschin, 2014; Smith et al., 2014;). In both cases, translating and applying small-scale processes into a larger scale entails collaboration with more actors (Laakso and Lettenmeier, 2015) as well as translational competence (Smith, 2007). Scalability can be demonstrated through the evaluation of scalable properties of solutions. Exemplary insights with regards to scalability can be gained via related feasibility studies including engagement of actors working at targeted scales. Actual efforts to take experimental results and scaling them out or up go beyond mere indication of scalability. A typical indicator is the independence of measures from changing governance systems on different scales.

An illustrative example of scalability as an output of an experiment is reported by Trencher et al. (2014a) where results from building and mobility experiments in the 2000-Watt Society Basel Pilot Region are shared with industry and government stakeholders across Switzerland, to foster change in policy and industry practice on the national level.

The evaluative question for this feature is: *Does the transition experiment indicate the potential for and how outputs can be scaled out to broader applications or up to higher hierarchical levels?*

Accounting for unintended consequences associated with up-take

In some contexts, up-take of sustainability solutions may generate both positive and negative unintended consequences (Evans and Karvonen, 2011; Smith et al., 2014). Careful consideration of potential interactive effects is necessary for anticipation and evaluation of the risks and opportunities related to transferring and scaling experiments. In particular, when processes of an experiment are applied in contexts with different characteristics or if up-taking exposes an experiment to changed dynamics. Typical indicators are consideration of rebound effects, long-term consequences, and the potential for co-optation and offsetting of sustainability gains.

An illustrative example for reducing the risks of unintended consequences as outcome of a transition experiment is the self-build construction package for harvesting rain-water in north eastern Brazil reported by Smith et al. (2014). The up-take of the experiment contained self-build aspects to enhance community interactions and empower people instead of creating dependencies on local elites.

The evaluative question for this feature is: *Does the transition experiments account for unintended consequences that are associated the up-take of sustainability solutions?*

3.2 Outcome Features

Outcomes refer to sustainability-related accomplishments of the experiment, and provide a basis for examining the extent to which a transition experiment contributed to sustainability (Forrest and Wiek, 2014; Wiek et al., 2015). Reporting on sustainability transition experiments often fails to provide a comprehensive appraisal of the resulting sustainability effects. Good appraisals are not easy because they face two competing demands. They need to apply a consistent set of criteria to allow comparison of outcomes among experiments. But they must also recognize that the outcomes may vary depending on the focus of the experiment (e.g. on water, food, energy or neighborhood development) and the specifics of the context. We have therefore chosen to evaluate sustainability outcomes by adopting an established set of comprehensive criteria as a common framework and then specify the criteria for the particular cases and contexts (Gibson, 2006; Gibson et al., 2005). Bearing in mind that not all features apply to every experiment, this approach supports evaluations that deliver comparable findings about sustainability outcomes.

3.2.1 Socio-ecological integrity

Socio-ecological integrity is a sustainability requirement that recognizes the interdependence of human well-being and bio-physical conditions (Gibson et al., 2005, p. 95-98). Operationalizing this feature for sustainability transition experiments in urban planning requires for instance harmonizing physical structures and respective human activities (Section 3.1.4) with biophysical processes and elements (Luederitz et al., 2013). It involves preventing degradation or compromising of ecosystem services and reducing overall demands on already stressed life-support systems, enhancing the regenerative capacity of natural resources, and as a last resort offsetting unavoidable adverse impacts (Lamorgese and Geneletti, 2013). Typical indicators are new green walls and roofs, ecosystem-based spatial planning including adapted user behavior, and new, improved or prioritized habitat (i.e. blue and green infrastructure).

An illustrative example for ensuring socio-ecological integrity as outcome of a transition experiment is the tree and shade program that was implemented to mitigate negative urban sprawl effects and ensure recreation of life-support functions in Phoenix, United States reported by Bernstein et al. (2014).

The evaluative question for this feature is: *Do the transition experiment's outputs strengthen socio-ecological integrity?*

3.2.2 Livelihood sufficiency and opportunity

Human well-being depends on sufficient access of individuals and communities to what is needed for a decent life. This includes ensuring availability of opportunities for exercising positive human powers and capabilities in the specific context (Gibson et al., 2005, p. 98-

101). In water governance cases, for example, operationalizing this feature requires that built capacities (Section 3.1.1) and structural changes (Section 3.1.4) support human prosperity. It includes providing long-term access to water with sufficient quality and quantity to satisfy people's basic livelihood needs, enhance their psycho-physical well-being, and pursue economic activities while also maintaining ecological functions (Larson et al., 2013). Typical indicators are access to potable water and availability of water.

An illustrative example for livelihood sufficiency and opportunity as an outcome of a transition experiment is the LED lighting introduction initiative implemented by Columbia University in the Millennium Villages Project in Malawi. Adkins et al. (2010) report that following the experiment village inhabitants saved significantly in kerosene expenditures and reported higher levels of satisfaction regarding lighting quality.

The evaluative question for this feature is: *Do the transition experiment's outputs enhance livelihood sufficiency and opportunity?*

3.2.3 Intra- and intergenerational equity

This feature refers to sufficient and effective choices that reduce disparity between the rich and the poor and enhances future generations' opportunities to pursue sustainable lives (Gibson et al., 2005, p. 101-105). Again in water governance cases, operationalizing intra- and intergenerational equity for water management requires that actionable knowledge (Section 3.1.2), built capacity (Section 3.1.1), and structural changes (Section 3.1.4) improve equity. It includes enhancing life-support systems to meet everyone's basic needs and sharing social and economic benefits and costs between upstream and downstream users. In addition, decision-making is required that improves long-term renewability of freshwater resources and supports efficient and wise use of water (Shah and Gibson, 2013). As such, experiments go beyond inclusion and participation of a diverse array of social groups into creating opportunities in actively empowering them to be part of on-going and future sustainability transitions. Typical indicators are the creation of opportunities for various social groups, particularly those least privileged, and ensuring equity between providers and beneficiaries.

An illustrative example for intra- and intergenerational equity as an outcome of a transition experiment is the Community Watershed Stewardship Program in Portland, United States, as reported by Miller et al. (2015). In collaboration with the university the program experimented with application procedures, messaging and outreach to increase the number of projects that involved underrepresented communities while producing watershed health benefits.

The evaluative question for this feature is: *Do the transition experiment's outputs improve intra- and intergenerational equity?*

3.2.4 Resource maintenance and efficiency

Creation of sustainable livelihoods for all requires the reduction of demands on the biosphere that jeopardize long-term socio-ecological integrity. That in turn entails cutting material and energy use per unit of benefit (Gibson et al., 2005, p. 105-107). Operationalizing this feature for agricultural energy production requires that structural changes (Section 3.1.4) ensure benign production, support soil fertility, reduce greenhouse gas emissions and consider rebound effects. Key means include the application of cleaner production technologies and sustainable agricultural practices. Maximizing the use of resources through co- and by-production, restoring soil fertility of production land, and minimizing greenhouse gas emissions along the production chain are also crucial components. It is critical to consider rebound effects that occur where material or energy efficiency gains facilitate greater consumption (e.g. when increased vehicle efficiencies encourage more car travel) (Duarte et al., 2013). Typical indicators are cradle-to-cradle or "Benign by Design" approaches, reduction in resource consumption, and efficiency gains in agricultural energy production.

An illustrative example for resource maintenance and efficiency as an outcome of a transition experiment is the replacing of halide lamps with Light Emitting Diode lights at Yale University, United States reported by Cole and Srivastava (2013).

The evaluative question for this feature is: *Do the transition experiment's outputs contribute to overall resource maintenance and efficiency?*

3.2.5 Socio-ecological stewardship and democratic governance

This feature refers to arrangements that support individual and collective engagement in sustainability decision-making (Gibson et al., 2005, p. 107-111). Operationalization to municipal planning and policy-making requires participants to address related aspects in actionable knowledge (Section 3.1.2), built capacities (Section 3.1.1), accountability (3.1.3) and structural changes (Section 3.1.4). Improving governance for sustainability may involve creating and maintaining a flexible decision-making framework and fostering ongoing collaborative decision-making processes with actors at the municipal level. In addition, social inclusion, involvement and a shared sense of ownership of collective decisions as well as human-nature relations need to be ensured in all facets of everyday life through government actors, business, and civil society (Stuart et al., 2014). Experiments also function as safe operating spaces for socio-ecological innovations (Frantzeskaki and Tefrati, 2016) that can, amongst others, foster literacy for self-governance and expression of democratic beliefs in alignment with sustainability values. Typical indicators are participatory settings, collaboration among different actors, knowledge co-production, strengthened human-nature relationships, and effective public input into municipal decision-making.

An illustrative example for improved socio-ecological stewardship and democratic governance as an outcome of a transition experiment is the re-opening of a community center in Rotterdam, Netherlands reported by Wittmayer et al. (2014). Inhabitants of a deprived neighborhood were empowered to engage in self-maintenance of community space.

The evaluative question for this feature is: *Do the transition experiment's outputs build or support socio-ecological understanding and democratic governance?*

3.2.6 Precaution and adaptation

The feature of precaution and adaptation captures the importance of acknowledging uncertainty and of anticipating and avoiding unpredictable risks. Precautionary approaches, creation of learning opportunities and preparation for surprises are essential for operationalization (Gibson et al., 2005, p. 111-113). The application of this feature in the evaluation of an aquaculture operation requires actionable knowledge (Section 3.1.2), built capacities (Section 3.1.1) and structural changes (3.1.4) to reflect on uncertainties and apply adaptive approaches. Key considerations include capturing the impacts of changes in fishing practices, enhancing capacities to monitor changes over time, and generating knowledge on future demands (Vincent and Morrison-Saunders, 2013). Typical indicators are risk-averse and cautious approaches, comprehensive risk analysis, and measures that explicitly address environmental degradation.

An illustrative example for precaution and adaptation as an outcome of a transition experiment is reported by Voytenko et al. (2015) in an initiative to integrate use of green and blue infrastructure to cope with storm water in New Kiruna City, Sweden. Contrary to the conventional approach to use piped networks, multifunctional green areas are utilized. With regards to current and future climate change impacts and other urban challenges, knowledge and tools were also developed for integrated urban storm water management.

The evaluative question for this feature is: *Do the transition experiment's outputs ensure precaution and adaptation?*

3.3 Process Features

Processes are a sequence of actions conducted in sustainability transition experiments. The particular actions and their sequence are critical for creating desired outputs. Process features are structured sequence of actions, sound methodology, collaboration, reflexivity and learning, and transparency (Forrest and Wiek, 2014). Since process and outputs often become intertwined during the experimentation, performed processes are as important as the generated outputs.

3.3.1 Sequence of actions

The sequence of actions in experimentation needs to include (Bernstein et al., 2014; Karvonen and van Heur, 2014; Laakso and Lettenmeier, 2015):

(i) Defining a baseline and a goal for the interventions

(ii) Creating a specific set-up to administer interventions

(iii) Measuring the effects of the interventions against the baseline and the goal

(iv) Evaluating the effects against sustainability criteria

(v) Offering evidence-supported recommendations on how to implement the results

Actions include scientific activities as well as, for example, managerial tasks when administering interventions. Action (v) includes processes and mechanisms that stimulate considering the experiment from a whole system perspective (Westley and Miller, 2003). Typical indicators are the adequate planning of actions and their interference in the timeline of the experiment, the completeness of actions as well as engaging the right participants and the right information.

An illustrative example for a sequence of action in a transition experiment is reported by Laakso and Lettenmeier (2015). Following the quantification of household consumption and the definition of sustainable material footprints, household specific visions were co-created and roadmaps developed through backcasting. The results from household experimentation were evaluated against the co-created visions and sustainable material footprints. Finally, a “Future Workshop” was conducted with relevant practitioners and decision-makers offering evidence supported recommendation on how to mainstream solutions.

The evaluative question for this feature is: *Is the transition experiment structured into a meaningful sequence of actions?*

3.3.2 Sound methodology

Sound methodology comprises the methods that are applied in each action of the experiment (see above). The pool includes, among others, methods for intervention design (e.g. problem analysis, visioning, strategy development, etc.), assessment, monitoring and evaluation (Bernstein et al., 2014; Ceschin, 2014; Davies and Doyle, 2015). This gives emphasis to *rigorous but broad and flexible* methods that promote transformational change over conventional approaches with a narrower focus on collecting and analyzing data. Typical indicators are structured procedures for generating outputs and the adequacy of methods for the respective action.

An illustrative example for a sound methodology in a transition experiment can be reviewed in Davies and Doyle (2015) reporting on an experiment to transform household consumption across the Republic of Ireland and Northern Ireland. The methodology included sound methods for baseline and goal definition, intervention design, as well as monitoring and evaluation.

The evaluative question for this feature is: *Does the transition experiment adopt a sound methodology to conduct the experiment?*

3.3.3 Collaboration

Collaboration in the context of transition experiments refers to: the participants of experiments (the collaborators), the mechanisms through which collaboration is facilitated (the participatory-setting) and the modes of interactions (the intensity of collaboration) (Juujärvi and Pesso, 2013; Tams and Wadhawan, 2012; Trencher et al., 2014a). Participants of experiments vary according to the focus and phase but typically include, among others, researchers, practitioners, and the public (Brown et al., 2003; Iwaniec and Wiek, 2014; Wittmayer et al., 2014). Participants need to be carefully selected to avoid power imbalance or excluding marginalized groups from the experiment (Wittmayer and Schäpke 2014). Participatory settings are the engagement procedures including focus groups, stakeholder workshops and more dynamic processes such as participatory modeling (Bernstein et al., 2014; Liedtke et al., 2015; Schreuer et al., 2010). In the preparation and the core phase of the experiment scientific and non-scientific actors collaborate through inter- and transdisciplinary approaches. Respective modes of interactions include information sharing, consultation, collaboration, and empowerment (Bernstein et al., 2014; Vandevyvere and Nevens, 2015). This feature also captures educational settings in which students participate in the experiments (Ceschin, 2014; Trencher et al., 2014b; Wiek and Kay, 2015). Typical indicators are affiliations of participants and their roles, information flows, decision-making procedures, and interactions.

An illustrative example for collaboration in a transition experiment is the revitalization of public space in Phoenix, United States, as reported by Wiek et al. (2015). The experiments were designed and conducted with various external stakeholders including an elementary school, the school district, the county department on public health, and the city service department who provided funds, helped in the co-design, and were active in the implementation (e.g. painting, planting, negotiating, etc.).

The evaluative question for this feature is: *Does the transition experiment facilitate collaboration among relevant stakeholders in the experimentation process?*

3.3.4 Reflexivity and learning

Reflexivity and learning refer to the iterative analysis of all components of the experiment (Evans and Karvonen, 2014; van Mierlo and Beers, 2015). This involves the components, processes and actors involved in the experiment as well as it demands recognizing and reflecting upon the broader institutional context, issues of power, privileges, legitimacy and aspects rendering salience (Loorbach et al., 2015). Learning based on reflexivity throughout the experiment allows for changing and adapting processes to generate desired outputs (Moore et al., 2005; van Buuren and Loorbach, 2009; Vergragt and Brown, 2007). In this context, first order learning refers to changing given processes making them more efficient and effective. Second order learning involves developing new processes as well as reinterpreting the purpose and function of given activities – often crucial for transformational change. Second order learning can occur if participants with different worldviews collaborate in the experiment. Typical indicators are the presence of a shared learning agenda and dedicated points of reflections such as meetings to explicitly reflect on the experiment, review processes, as well as changes of the experimentation process.

An illustrative example for reflexivity and learning in a transition experiment are the activities related to the piloting of eco-innovations in Paris, France, as reported by Audet and Guyonnaud (2013). For example, the innovation experiments conducted by the Fondaterra Foundation were remodeled and framed as transition initiatives based on collaborative educational seminars to strategically promote and harness change.

The evaluative question for this feature is: *Does the transition experiment foster reflexivity and learning throughout the process?*

3.3.5 Transparency

Transparency refers to open and truthful reporting on intentions and pursued actions in the experimentation process. It includes documentation and publishing of the process, data, decision-making and conclusions ensuring the possibility for all actor groups to access related information (Evans and Karvonen, 2014; Iwaniec and Wiek, 2014; Ryan, 2013). It also captures indication of researchers' accountability for the experimentation process. Typical indicators are openly published results, reports that explicate assumptions and intentions, and documentation of the decision-making process.

An illustrative example of transparency as part of the process of a transition experiment is to explicitly highlight the underlying assumptions on which interventions in Melbourne, Australia, were based, as reported by Ryan (2013). Such transparency enhancing processes prevented antagonism regarding the outputs of the urban experiment amid polarized political debates.

The evaluative question for this feature is: *Does the transition experiment ensure transparency throughout the process?*

3.4 Input Features

Inputs are contributions to and investments in the sustainability transition experiment including awareness, commitment, expertise, trust, as well as financial, and other types of support (Wiek et al., 2015; Forrest and Wiek, 2014). Although inputs are often thought of as prerequisites that need to be in place prior to experimentation, inputs remain of vital importance throughout experimentation.

3.4.1 Awareness

Awareness refers to the ability and consciousness of participants to acknowledge the need for radical real-world changes prior to and during their engagement in the experiment (Bos and Brown, 2012; Nevens and Roorda, 2014). It involves the motives and intentions of participants to participate and helps protect experiments from loss of momentum during later phases (Moore et al., 2005; Wiek et al., 2014). Typical indicators are sustainability-related track records of participants, and participants' general awareness of the sustainability issues tackled by the experiment.

An illustrative example of awareness as input into a transition experiment is declaration of the city council to become a carbon neutral city four years before related experiments were initiated in the City of Ghent, Belgium, as reported by Nevens and Roorda (2014).

The evaluative question for this feature is: *Does the transition experiment involve participants that are aware of the need for transformational change pursued through the experiment?*

3.4.2 Commitment

Commitment refers to willingness, promises, positive attitudes and interests of involved participants to explore "intentionally radical" instead of "incremental or entropic" changes (Karvonen and van Heur, 2014, p. 387). This includes researchers and non-academic participants' motivation to exceed monetary or reputational benefits and pursue collaboratively taken decisions driven by intrinsic motivations to contribute to a common goal (Ceschin, 2014; Moore, et al., 2005). Accountability as a transition experiment output is often dependent on a critical level of initial commitment (as input feature). Typical indicators are that participants' agreement to deliver tasks on time, participants' engagement in decision-taking, and continuous participation in the experimentation.

An illustrative example of commitment as input into a transition experiment is the intrinsic interests of participants in the integrated urban water management in Sydney, Australia, reported by Bos and Brown (2012). Participants' commitment facilitated a meaningful dialogue between different interests, which resulted in political commitment towards the initiative.

The evaluative question for this feature is: *Does the transition experiment involve participants committed to carrying out the experiment?*

3.4.4 Expertise

Expertise, including professional skills and experiences, is a critical input for sustainability transition experiments (Wiek et al., 2015). It includes recognized professional skills and experiential techniques to research, craft, guide, decide and judge experimentation. Furthermore, it refers to reflexive capacities and abilities to learning from the experiment as well as expertise in issues of ethics, transparency, and power relations (Wittmayer and Schäpke 2014). Typical indicators include related work experience and academic and professional degrees and training of the participants.

An illustrative example of expertise as input into a transition experiment is a participatory technology assessment in Graz, Austria, reported by Schreuer et al. (2010). Expertise was provided by professionals from the municipal department for energy, fuel cell development, research institutes and an energy network – critical for designing an experiment on fuel cells.

The evaluative question for this feature is: *Does the transition experiment involve participants who possess the necessary skills and knowledge to carry out the experiment?*

3.4.5 Trust

Trust refers to the mutual willingness to collaborate on equal footing, reconcile divergent worldviews, as well as acknowledge different interests (Bernstein et al., 2014; Vandevyvere and Nevens, 2015). Since experiments are particularly susceptible to failure (Nevens et al., 2013), engendering trust amongst participants is important for building participants' confidence in the processes and the potential outcomes of the experiment, making a collaborative experiment and joint addressing of potential difficulties possible. In addition, the process of co-creating knowledge and shared evaluation of the experiments demands trust as a source of open, truthful and collaborative exchange, particularly as interests and reputation are potentially at stake (Trencher at al., 2015). Typical indicators are participants' attitudes toward other participants, ability to speak one's mind, and willingness to rely on others' judgments and capacities.

An illustrative example of trust as input into a transition experiment is the engagement of university researchers in interventions in Melbourne, Australia, as reported by Ryan (2013). The implementation of future exhibitions and tours was welcomed by local councils because they were incorporated into long-term visions and short-term actions proposed by an institution that was seen as independent from commercial developers and the government.

The evaluative question for this feature is: *Does the transition experiment involve participants who trust each other?*

3.4.6 Support

Support refers to structural, financial and nonfinancial resources as well as assistance from public and private authorities in preparing and executing sustainability transition experiments (Bos and Brown, 2012; Vandevyvere and Nevens, 2015). It also includes voluntary and in-kind contributions and donation of work beyond normal obligations (Moore et al., 2005; Wiek et al., 2015). Typical indicators are available funds, positions, hours of voluntary contributions and endorsements from actors and institutions.

An illustrative example of support as input into a transition experiment is reported by Frantzeskaki et al. (2014). A "Floating Pavilion" was constructed as pilot project for testing social, technological and economic aspects of floating apartments that are planned for the regeneration of Rotterdam's harbor (the Netherlands). Besides in-kind funding and support by private companies, public authorities and research institutes, the financial investments amounted to 5.5 € million.

The evaluative question for this feature is: *Does the transition experiment secure sufficient support for the experimentation?*

3.5 Summary

Overall, the above scheme provides a structured appraisal to assist with sustainability transition experiments becoming more effective and efficient. In addition, we intend to facilitate and accelerate learning across different experiments. Since the description of the evaluative scheme is generic, application to empirical experiments requires contextualizing, concretizing and adapting each feature. We summarize the presented features in box 1 and through instructive definitions provide tentative principles for designing sustainability transition experiments.

Box 1: The tentative evaluation scheme for appraising sustainability transition experiments

Criteria Set: Outputs (I)

Built capacities
Empower participants to act sustainably in everyday decision-making and practices through educating them in cognitive, practical and interpersonal competencies and enable to internalize required skills and activate new behavioral patterns.
Evaluative question: *Does the transition experiment build capacities in participants to generate sustainability solutions?*

Actionable knowledge
Generate evidence-supported instructions that have been tested on effectively solving a sustainability problem within the defined experimental setting including guidelines on how to most effectively transition from the current to the desired state.
Evaluative question: *Does the transition experiment generate actionable knowledge that provides evidence on how to generate sustainability solutions?*

Accountability
Ensure confidence and commitment of participants to implement results generated by the experiment and their dedication to positive change.
Evaluative question: *Does the transition experiment build confidence and commitment for generating and realizing sustainability solutions?*

Changes in physical structures
Create new or transform existing buildings, infrastructures, technologies and products that are radically different from existing ones.
Evaluative question: *Does the transition experiment generate physical changes that support solutions for the identified sustainability problem?*

Changes in social structures
Create new or transform existing networks and organizations, values and norms, rules and policies, behavior and practices, and discourses that are radically different from existing ones.
Evaluative question: *Does the transition experiment generate societal changes that support solutions for the identified sustainability problem?*

Transferability
Create generalizable lessons learned regarding processes through to outcome of the experimentation that are applicable to different contexts.
Evaluative question: *Does the transition experiment indicate how the sustainability solution can be transferred to different contexts?*

Scalability
Create generalizable knowledge that facilitates the up-take of experiment results in system-wide applications
Evaluative question: *Does the transition experiment indicate the potential for and how outputs can be scaled out to broader applications or up to higher hierarchical levels?*

Accounting for unintended consequences associated with up-take
Reflect on and identify circumstances that have the potential to generate unintended consequences through the up-take of sustainability solutions.
Evaluative question: *Does the transition experiments account for unintended consequences that are associated with the up-take of sustainability solutions?*

Criteria Set: Outcomes (II)

Socio-ecological integrity
Harmonize human well-being with the biophysical processes and elements, preventing degradation of ecosystems and reducing overall impacts and threads to the life-support system.
Evaluative question: *Do the transition experiment's outputs strengthen socio-ecological integrity?*

Livelihood sufficiency and opportunity
Ensure sufficient access of individuals and communities to what is needed for a decent life and create opportunities for positively exercising power and capabilities.
Evaluative question: *Do the transition experiment's outputs enhance livelihood sufficiency and opportunity?*

Intra- and intergenerational equity
Ensure sufficient and effective choices that reduce gaps between the rich and the poor and enhance opportunities of future generation to pursue sustainable lives.
Evaluative question: *Do the transition experiment's outputs improve intra- and intergenerational equity?*

Resource maintenance and efficiency
Create sustainable livelihoods for all while reducing threats that jeopardize the long-term socio-ecological integrity and cutting material and energy use per unit of benefit.
Evaluative question: *Do the transition experiment's outputs contribute to overall resource maintenance and efficiency?*

Socio-ecological stewardship and democratic governance
Provide arrangements that support individual and collective sustainability decision-making fostering ongoing collaborative actions, social inclusion and ownership.
Evaluative question: Do the transition experiment's outputs build or support socio-ecological understanding and democratic governance?

Precaution and adaptation
Acknowledge uncertainty and avoid uncomprehended risks, creating learning opportunities and preparing for surprises and change.
Evaluative question: *Does the transition experiment's outputs ensure precaution and adaptation?*

Criteria Set: Processes (III)

Sequence of actions
Document the chronological chain of activities including the act of doing within the experiment, its purpose, the delivered actions and the scope of interventions.
Evaluative question: *Is the transition experiment structured into a meaningful sequence of actions?*

Sound methodology
Ensure that the experiment is facilitated through sound methods, including problem analysis, visioning, strategy development, as well as monitoring and evaluation
Evaluative question: *Does the transition experiment adopt a sound methodology to conduct the experiment?*

Collaboration
Provide participatory settings for collaboration of participants and ensure empowerment of participants.
Evaluative question: *Does the transition experiment facilitate collaboration among relevant stakeholders in the experimentation process?*

Reflexivity and Learning
Ensure the analysis of actions, structures, processes and outputs, as well as iterative and recursive learning.
Evaluative question: *Does the transition experiment foster reflexivity and learning throughout the process?*

Transparency
Ensure open and truthful reporting on intentions and pursued actions within the experimentation process.
Evaluative question: *Does the transition experiment ensure transparency throughout the process?*

Criteria Set: Inputs (IV)

Awareness
Enable participants' consciousness of and ability to acknowledge the need for radical real-world changes prior to their engagement in the experiment.
Evaluative question: *Does the transition experiment involve participants that are aware of the need for transformational change pursued through the experiment?*

Commitment
Cater for willingness, promises, positive attitudes and interests of involved participants to explore intentionally radical instead of incremental changes
Evaluative question: *Does the transition experiment involve participants committed to carrying out the experiment?*

Expertise
Ensure expertise of participants in sustainability transition experiments including widely recognized professional skills and experiential techniques to research, craft, guide, decide and judge experimentation.
Evaluative question: *Does the transition experiment involve participants who possess the necessary skills and knowledge to carry out the experiment?*

Trust
Cater for mutual willingness of and between researchers and non-academic participants to rely on actions of other members of the sustainability transition experiment.
Evaluative question: *Does the transition experiment involve participants who trust each other?*

Support
Ensure structural, financial and nonfinancial resources as well as assistance from public and private authorities in preparing and executing sustainability transition experiments.
Evaluative question: *Does the transition experiment secure sufficient support for the experimentation?*

4. Discussion

Although differences in transition approaches have been highlighted on the theoretical level (Markard et al., 2012; van den Bergh et al., 2011), little attention has been paid to the diversity of practical sustainability and transition experiments around the world (Trencher et al., 2014b). Currently undertaken transition experiments come in various shapes and forms. The presented evaluative scheme is designed to be applicable to a broad range of sustainability transition experiment types. The presented features are not based on a single theoretical interpretation of transition experiments. Rather, the scheme includes a broad array of features that are of importance across different framings of sustainability transition experiments. Thus, the evaluative scheme allows for comparative evaluations of various experiments to identify critical success factors (cf. Forrest and Wiek, 2014, 2015). It offers a coherent set of principles for designing experiments (see the instructive definitions of each feature in box 1) and evaluative questions that can enhance the reflexive nature of initiatives and their contribution to sustainability transitions. The following discussion is framed by the four criteria that informed the development of the scheme, i.e. being generic, comprehensive, operational, and formative.

4.1 Is the evaluative scheme generic?

Cross-case learning between and among different sustainability transition experiments requires generically defined features (Macmillan et al., 2001; Rogers, 2008). The presented scheme was developed with regards to transition experiments framed through various approaches. The features cover a broad range of requirements intended to be applicable to sustainability transition experiments independent from their specific conceptual framing.

Application of the scheme requires contextualization of the outlined features. While generic attributes guide the evaluation independent of the context, application to a particular experiment does require the integration of certain needs and context specifics (Gibson, 2006). The illustrative examples are intended to facilitate this process. In addition, local concerns and characteristics need to be drawn from studies in similar contexts, relevant public documents and integration of local knowledge. Contextualization, however, should not jeopardize the common ground required for cross-case comparison. For this purpose it suffices that evaluations only capture the essential characteristics of the experiment.

The scheme is an invitation to researchers and practitioners to engage in reflexive evaluations and advance the presented features. Since the scheme is intended as a "working list" of general requirements, features could be merged, subdivided, or revised. The scheme is a "living" construct open to critical application, learning, and improvement. In this spirit, the evaluative scheme serves as a starting point for a platform of exchange on the experiences of researchers and practitioners with the evaluation of sustainability transition experiments.

4.2 Is the evaluative scheme comprehensive?

A comprehensive evaluative scheme needs to cover the different dimensions including *all* features critical to the nature of sustainability transition experiments (Forrest and Wiek, 2014; McLaughlin and Jordan, 2010). We adopted the established logical model of evaluation to ensure basic comprehensiveness (Figure 1). The scheme is comprehensive as it describes the different dimensions of the experiment: the use of resources (*inputs*) in *processes* that generate *outputs* and evaluate them with regards to sustainability (*outcomes*), including a tentatively comprehensive collection of critical features from a broad range of experiment types.

The scheme will only be useful if the evaluation is rigorous. This implies applying the scheme to the full extent in order to capture *all* features critical to a transition experiment and to allow for cross-case comparison between different experiments. The evaluative questions need to be answered with scrutiny to support honest evaluation. The objective of being comprehensive also implies that sufficient reasons are being provided if features are added or dismissed. All features are justified with relevant literature to reduce arbitrariness – and this should be a rule for proposed changes, too. Following the presented scheme would also reduce getting caught in the politics of evaluation (see e.g. Bulkeley and Betsill, 2013). However, the presented scheme is only practical when there is commitment to rigorous evaluation and capacity to use the results.

There are three limitations to the comprehensiveness of the scheme. First, it focuses on experiments, even if they aim at a larger goal (sustainability transition), which requires cumulative evaluations. Sustainability outcomes will be at least complementary or even mutually reinforcing. Encouraging and reproducing positive effects is the intent of sustainability transition experiments. However, accomplishing only a small selection of outcome features will not be sufficient for levering sustainability. Transition experiments are often conducted through transition labs. If the overall contribution of a sustainability transition lab is evaluated, all outcome features need to be integrated in the immediate and long-term for seeking reinforcing benefits and multiplying gains (Gibson, 2006). Thus, carefully choosing the right timing for evaluation is important. However, not every type of evaluation is capable of capturing time delays. Since not all downstream activities may fall within the range of evaluation, the successful on-going up-take of experiments may exceed the scope of evaluation timeframes. Finally, ex-post evaluation should be planned for from the start of an experiment to ensure that required actions are carried out (e.g. baseline assessment).

Second, actors may evaluate a given experiment in different ways, depending on their normative orientation and respective judgment (Smith and Raven, 2012; Leach et al., 2010). The appraisals might vary depending on the framing of the experiment, too (Smith et al., 2014; Fressoli et al., 2014). This applies to the outcomes – whether an experiment is successful or not – as well as to the processes – whether they are appropriate and just, leading to different judgments on features critical for the experiment. Processes and content are intertwined in transition experiments, which means that the generated outcomes are as important as the process through which they are produced (Rotmans and Loorbach, 2009; Robinson 2003). Independent of the actor groups involved, vested interests, power relations, and political realities will influence evaluation efforts. The presented scheme is intended to facilitate a structured debate regarding the proposed features and process, functioning as a guiding tool for learning. In addition, the comprehensive character of the scheme supports the uncovering of issues not adequately addressed through the evaluation or the experiment.

Third, although the presented scheme can inform the design of experiments, it does not account for causal relations among different features. However, based on our experience and the reviewed literature, features of one dimension may follow a logic order (see Section 3.1), but features of different dimensions may as well be connected through causal relations. For example, a functional technology as an output of an experiment (Section 3.1.2) is achieved by adopting a sound methodology (Section 3.3.1) and through collaboration (Section 3.3.3), but ultimately depends on participants' awareness (Section 3.4.1) and commitment (Section 3.4.2). Application to multiple experiments will allow identifying the influencing factors, relations, and weights. Studies applying the scheme may also identify causal mechanisms through process tracing from inputs to outcomes via intermediate processes and outputs (Forrest and Wiek, 2014; George and Bennett, 2005). Such causal mechanisms, plus cumulative data from multiple studies provide the basis for theory building and designing further evaluative studies targeting specific hypotheses about what makes an experiment succeed or fail (Yin, 2009). The focus on experiments as the smallest unit or stepping stone of sustainability transitions provides possibilities to inform long-term transition processes (Rotmans, 2005).

4.3 Is the evaluative scheme operational?

Operationalization is required to enable practical application of the scheme (Bornmann, 2013). We intend to facilitate this through typical indicators and evaluative questions. Following the numbering in Figure 1, evaluators are equipped with the essential questions for appraising experiments and provided with specific sources for operationalization. Additional research is needed to further operationalize the scheme and provide samples of exemplary operationalization.

The operationalization of generic features poses reflexive questions, including: “Who evaluates whom and for what purpose?” We argue for the application of the scheme by core members of the experiment or at least that they support external evaluation. When being applied by practitioners in a utilization-focused evaluation, the scheme enhances the strategic orientation, coherence and impact of the experiment (Patton, 2012). In addition, participating in the process of evaluation through facilitation of data collection creates dedicated points of reflection. This provides an informal opportunity for learning that otherwise would not be present. For researchers, the scheme could aid evaluation of the transformational potential of experiments, also enabling cross-case comparison of experiments. While evaluation contributes to learning of researchers and practitioners, it may also serve the increasing demands by funders for accountability. However, this creates tensions between short-term accountability and long-term sustainability transitions (Regeer et al. 2016). This reflects conflicts between experiments and their respective contexts (ibid). Accordingly, evaluation is not a neutral, objective task, but influenced by power and interests (Evans and Karvonen, 2014; Smith et al., 2014; Wamsler et al., 2014). Therefore, evaluators need to avoid, for example, framing least privileged groups as beneficiaries without giving them a proper say in the decision-making (Evans and Karvonen, 2014). This raises question of legitimacy (in the social sphere) and accuracy and relevancy (in the scientific sphere) – which call for transparency about goal and process of each evaluation.

Making the scheme fully operational and applicable requires to embed it into an evaluation methodology, which requires coping with various challenges as indicated in a study by Wiek et al (2014). Such a methodology needs to specify methods for gathering data on different features as well as for analyzing and visualizing results. It needs to account for challenges related to the politics of evaluation as well as ambiguity related to the purpose and outcome of the evaluation. Such methodology would support coherent, yet reflexive, application of the scheme to a large number of transition experiments. In addition, it would support multi-step evaluation processes and coherent ways of summarizing and aggregating results. Developing an evaluation methodology is a desirable next step, which needs to be informed by application of the scheme.

4.4 Is the evaluative scheme formative?

An evaluative scheme needs to support sustainability transition experiments to become more effective and efficient. The application of the presented scheme as a formative tool therefore intends to improve designing experiments and improving ongoing experimentation. When the scheme is being used as guideline for designing experiments (*ex-ante evaluation*), evaluators can derive design principles from Box 1. The scheme functions as a checklist that channels the attention to essential items that need to be evaluated regarding their relevance for the experiment in question (e.g. which inputs need to be secured and what processes have to be carried out to generate outputs). Ex-ante evaluation allows the appraisal of prospective outputs with regards to their sustainability outcomes (following the big arrows in Figure 1).

The scheme can also be applied to completed experiments (*ex-post evaluation*). Evaluators can utilize the evaluative questions provided in Box 1. The scheme provides orientation for the evaluation by starting from the outputs evaluating them with regards to sustainability (outcomes), and working ‘backwards’ by tracking processes and inputs. Carefully choosing the right timing for evaluation is as important as the evaluation itself since an untimely appraisal might not do justice to an experiment and “out-score” its accomplishments. *Ex-post evaluation* should be planned for from the start of an experiment to support experiment design and implementation (e.g. to ensure attention to the need to conduct a baseline assessment).

In case of *formative evaluation* for improving on-going sustainability transition experiments, the design guidelines and evaluative questions presented in Box 1 are equally important. It offers the possibility to regularly appraise progress and shortcomings of experiments. To improve design and performance, evaluators can start at any evaluative dimension (Figure 1). While they reflect on the tentative design principles as well as on the evaluative questions, they also have to simultaneously work backwards to the inputs, and track forwards towards the targeted outcomes.

In addition, extending formative evaluation beyond solely improving experiments efficiency and effectiveness requires re-conceptualizing their contribution to overall societal change processes. This demands participants to engage in open and reflexive processes considering the goals and procedures of an experiment and facilitate cross-case comparison between different experiments. Finally, the presented scheme is only formative if there is commitment to evaluation and capacity to use the outcomes. Evaluation requires financial and human resources and, ideally, is already planned for when designing the experiment proposal.

5. Conclusion

This article presents a tentative evaluative scheme for appraising individual sustainability transition experiments and facilitating their cross-case comparison. We propose a set of characteristics the scheme requires to be broadly applicable, practical, comprehensive and used to improve the performance of contemporary and future experiments. Following the basic logic model of evaluation, we reviewed sustainability transition experiments to identify features in the evaluative dimensions of inputs, processes, outputs and outcomes. Each feature was described (definitions), exemplified (indicators), illustrated (examples) and justified. The resulting evaluative scheme in general and with the discussed limitations is (i) *generic*, i.e., applicable to different types of sustainability transition experiment; (ii) *comprehensive*, i.e., captures all critical features of experiments; (iii) *operational*, i.e., ready for application; and (iv) *formative*, i.e., supports experiments in becoming more effective and efficient. While the presented scheme is neither finished nor a recipe for success, it serves as a basis for structured reflection and strategizing in support of experiments that help society to transition towards sustainability. We emphasize the need for applying the scheme to facilitate learning and accelerate progress across different experiments as well as for advancing evaluation of sustainability transitions. We encourage future research projects that apply, question and improve this framework to expand the evidence base for designing and conducting the next generation of sustainability transition experiments.

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6. References

Adkins, E., Eapen, S., Kaluwile, F., Nair, G., & Modi, V. (2010). Off-grid energy services for the poor: Introducing LED lighting in the Millennium Villages Project in Malawi. Energy Policy, 38(2), 1087–1097. doi:10.1016/j.enpol.2009.10.061

Audet, R., & Guyonnaud, M.-F. (2013). Transition in practice and action in research. A French case study in piloting eco-innovations. Innovation: The European Journal of Social Science Research, 26(4), 398–415. doi:10.1080/13511610.2013.850019

Avelino, F., Rotmans, J. (2009). Power in Transition: An Interdisciplinary Framework to Study Power in Relation to Structural Change. Eur. J. Soc. Theory 12, 543–569. doi:10.1177/1368431009349830

Bai, X., Roberts, B., & Chen, J. (2010). Urban sustainability experiments in Asia: patterns and pathways. Environmental Science & Policy, 13(4), 312–325. doi:10.1016/j.envsci.2010.03.011

Banerjee, A. V., Duflo, E., Glennerster, R., & Kothari, D. (2010). Improving immunisation coverage in rural India: clustered randomised controlled evaluation of immunisation campaigns with and without incentives. BMJ: British Medical Journal, 340, c2220. doi:10.1136/bmj.c2220

Bernstein, M. J., Wiek, A., Brundiers, K., Pearson, K., Minowitz, A., Kay, B., & Golub, A. (2014). Mitigating urban sprawl effects: a collaborative tree and shade intervention in Phoenix, Arizona, USA. Local Environment, (January 2015), 1–18. doi:10.1080/13549839.2014.965672

Bornmann, L. (2013). What is societal impact of research and how can it be assessed? a literature survey. Journal of the American Society for Information Science and Technology, 64(2), 217–233. doi:10.1002/asi.22803

Bos, J. J., & Brown, R. R. (2012). Governance experimentation and factors of success in socio-technical transitions in the urban water sector. Technological Forecasting and Social Change, 79(7), 1340–1353. doi:10.1016/j.techfore.2012.04.006

Bos, J. J., Brown, R. R., & Farrelly, A. M. (2013). A design framework for creating social learning situations. Global Environmental Change, 23(2), 398–412. doi:10.1016/j.gloenvcha.2012.12.003

Bos, J. J., Brown, R. R., & Farrelly, M. A. (2015). Building networks and coalitions to promote transformational change: Insights from an Australian urban water planning case study. Environmental Innovation and Societal Transitions, 15, 11–25. doi:10.1016/j.eist.2014.10.002

Brown, H. S., Vergragt, P., Green, K., & Berchicci, L. (2003). Learning for Sustainability Transition through Bounded Socio-technical Experiments in Personal Mobility. Technology Analysis & Strategic Management, 15(3), 291–315. doi:10.1080/09537320310001601496

Brown, H. S., & Vergragt, P. J. (2008). Bounded socio-technical experiments as agents of systemic change: The case of a zero-energy residential building. Technological Forecasting and Social Change, 75(1), 107–130. doi:10.1016/j.techfore.2006.05.014

Bulkeley, H., Betsill, M.M. (2013). Revisiting the urban politics of climate change. Env. Polit. 22, 136–154. doi:10.1080/09644016.2013.755797

Castán Broto, V., Bulkeley, H. (2013). A survey of urban climate change experiments in 100 cities. Glob. Environ. Change 23, 92–102. doi:10.1016/j.gloenvcha.2012.07.005

Ceschin, F. (2014). How the Design of Socio-technical Experiments Can Enable Radical Changes for Sustainability. International Journal of Design, 8(3), 1–21.

Cole, C., & Srivastava, C. (2013). Energy Blitz Leads to Measured Reductions on Campus: Students Embrace Campus as a Living Lab at Yale. Sustainability: The Journal of Record, 6(1), 37–41. doi:10.1089/SUS.2013.9893

Davies, A. R., & Doyle, R. (2015). Transforming Household Consumption: From Backcasting to HomeLabs Experiments. Annals of the Association of American Geographers, 105(2), 425–436. doi:10.1080/00045608.2014.1000948

Davies, A. R., Doyle, R., & Pape, J. (2012). Future visioning for sustainable household practices: spaces for sustainability learning? Area, 44(1), 54–60. doi:10.1111/j.1475-4762.2011.01054.x

Duarte, C. G., Gaudreau, K., Gibson, R. B., & Malheiros, T. F. (2013). Sustainability assessment of sugarcane-ethanol production in Brazil: A case study of a sugarcane mill in São Paulo state. Ecological Indicators, 30, 119–129. doi:10.1016/j.ecolind.2013.02.011

Evans, J., & Karvonen, A. (2011). Living Laboratories for Sustainability: Exploring the Politics and Epistemology of Urban Transition. In H. Bulkeley, V. Castán Broto, M. Hodson, & S. Marvin (Eds.), Cities and Low Carbon Transition (pp. 126–141.). London: Routledge.

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. International Journal of Urban and Regional Research, 38(2), 413–430. doi:10.1111/1468-2427.12077

Farrelly, M. A., & Brown, R. R. (2011). Rethinking urban water management: Experimentation as a way forward? Global Environmental Change, 21(2), 721–732. doi:10.1016/j.gloenvcha.2011.01.007

Ferguson, B. C., Brown, R. R., & Deletic, A. (2013). A Diagnostic Procedure for Transformative Change Based on Transitions, Resilience, and Institutional Thinking. Ecology and Society, 18(4), art57. doi:10.5751/ES-05901-180457

Forrest, N., & Wiek, A. (2014). Learning from success—Toward evidence-informed sustainability transitions in communities. Environmental Innovation and Societal Transitions. doi:10.1016/j.eist.2014.01.003

Forrest, N., & Wiek, A. (2015). Success factors and strategies for sustainability transitions of small-scale communities – Evidence from a cross-case analysis. Environmental Innovation and Societal Transitions, 1–19. doi:10.1016/j.eist.2015.05.005

Frantzeskaki, N., & Kabisch, N. (2016). Designing a knowledge co-production operating space for urban environmental governance lessons from Rotterdam, Netherlands and Berlin, Germany. Environmental Science & Policy, (2015), 1–9. doi:10.1016/j.envsci.2016.01.010

Frantzeskaki, N., & Tefrati, N. (2016). A transformative vision unlocks the innovative potential of Aberdeen City. In Theory and practice of governance of urban sustainability transitions. UK: Springer.

Frantzeskaki, N., Wittmayer, J., & Loorbach, D. (2014). The role of partnerships in “realising” urban sustainability in Rotterdam’s City Ports Area, The Netherlands. Journal of Cleaner Production, 65, 406–417. doi:10.1016/j.jclepro.2013.09.023

Geels, F., Raven, R. (2006). Non-linearity and Expectations in Niche-Development Trajectories: Ups and Downs in Dutch Biogas Development (1973–2003). Technol. Anal. Strateg. Manag. 18, 375–392. doi:10.1080/09537320600777143

George, A. L., & Bennett, A. (2005). Case Studies and Theory Development in the Social Sciences. Cambridge: MIT Press.

Gibson, R. B. (2006). Sustainability assessment: basic components of a practical approach. Impact Assessment and Project Appraisal, 24(3), 170–182. doi:10.3152/147154606781765147

Gibson, R. B., Hassan, S., Holtz, S., Tansey, J., & Whitelaw, G. (2005). Sustainability assessment: Criteria and Processes. London: Earthscan.

Hart, D. D., Bell, K. P., Lindenfeld, L. A., Jain, S., Johnson, T. R., Ranco, D., & McGill, B. (2015). Strengthening the role of universities in addressing sustainability challenges: the Mitchell Center for Sustainability Solutions as an institutional experiment. Ecology and Society, 20(2), art4. doi:10.5751/ES-07283-200204

Iwaniec, D., & Wiek, A. (2014). Advancing Sustainability Visioning Practice in Planning—The General Plan Update in Phoenix, Arizona. Planning Practice & Research, (November), 1–26. doi:10.1080/02697459.2014.977004

Juujärvi, S., & Pesso, K. (2013). Actor Roles in an Urban Living Lab: What Can We Learn from Suurpelto, Finland? Technology, (November), 22–27.

Karvonen, A., & van Heur, B. (2014). Urban Laboratories: Experiments in Reworking Cities. International Journal of Urban and Regional Research, 38(2), 379–392. doi:10.1111/1468-2427.12075

König, A. (2015). Towards systemic change: on the co-creation and evaluation of a study programme in transformative sustainability science with stakeholders in Luxembourg. Current Opinion in Environmental Sustainability, 16, 89–98. doi:10.1016/j.cosust.2015.08.006

Kemp, R., Schot, J., Hoogma, R. (1998). Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. Technol. Anal. Strateg. Manag. 10, 175–198. doi:10.1080/09537329808524310

Laakso, S., & Lettenmeier, M. (2015). Household-level transition methodology towards sustainable material footprints. Journal of Cleaner Production, 1–8. doi:10.1016/j.jclepro.2015.03.009

Lamorgese, L., & Geneletti, D. (2013). Sustainability principles in strategic environmental assessment: A framework for analysis and examples from Italian urban planning. Environmental Impact Assessment Review, 42, 116–126. doi:10.1016/j.eiar.2012.12.004

Lang, D.J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., Thomas, C.J. (2012). Transdisciplinary research in sustainability science: practice, principles, and challenges. Sustain. Sci. 7, 25–43. doi:10.1007/s11625-011-0149-x

Larson, K. L., Wiek, A., & Withycombe Keeler, L. (2013). A comprehensive sustainability appraisal of water governance in Phoenix, AZ. Journal of Environmental Management, 116, 58–71. doi:10.1016/j.jenvman.2012.11.016

Leach, M., Scoones, I., Stirling, A. (2010). Dynamic Sustainabilities: Technology, Environment, Social Justice. Earthscan, London. doi:10.4324/9781849775069

Leslie, H.M., Basurto, X., Nenadovic, M., Sievanen, L., Cavanaugh, K.C., Cota-Nieto, J.J., Erisman, B.E., Finkbeiner, E., Hinojosa-Arango, G., Moreno-Báez, M., Nagavarapu, S., Reddy, S.M.W., Sánchez-Rodríguez, A., Siegel, K., Ulibarria-Valenzuela, J.J., Weaver, A.H., Aburto-Oropeza, O. (2015). Operationalizing the social-ecological systems framework to assess sustainability. Proc. Natl. Acad. Sci. U. S. A. 112, 5979–84. doi:10.1073/pnas.1414640112

Liedtke, C., Baedeker, C., Hasselkuß, M., Rohn, H., & Grinewitschus, V. (2015). User-integrated innovation in Sustainable LivingLabs: an experimental infrastructure for researching and developing sustainable product service systems. Journal of Cleaner Production, 97, 106–116. doi:10.1016/j.jclepro.2014.04.070

Loorbach, D., Frantzeskaki, N., & Lijnis Huffenreuter, R. (2015). Transition Management: Taking Stock from Governance Experimentation. Journal of Corporate Citizenship, 2015(58), 48–66. doi:10.9774/GLEAF.4700.2015.ju.00008

Loorbach, D., & Rotmans, J. (2010). The practice of transition management: Examples and lessons from four distinct cases. Futures, 42(3), 237–246. doi:10.1016/j.futures.2009.11.009

Loorbach, D. (2010). Transition Management for Sustainable Development: A Prescriptive, Complexity-Based Governance Framework. Governance 23, 161–183. doi:10.1111/j.1468-0491.2009.01471.x

Luederitz, C., Lang, D. J., & Von Wehrden, H. (2013). A systematic review of guiding principles for sustainable urban neighborhood development. Landscape and Urban Planning, 118, 40–52. doi:10.1016/j.landurbplan.2013.06.002

Macmillan, S., Road, C., Steele, J., Austin, S., Engineering, B., Kirby, P., & Spence, R. (2001). Development and verification of a generic framework for conceptual design. Design Studies, 22(2), 169–191.

Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. Research Policy, 41(6), 955–967. doi:10.1016/j.respol.2012.02.013

Marshall, G.R. (2015). A social-ecological systems framework for food systems research: accommodating transformation systems and their products. Int. J. Commons 9, 881. doi:10.18352/ijc.587

McAlpine, C. A., Seabrook, L. M., Ryan, J. G., Feeney, B. J., Ripple, W. J., Ehrlich, A. H., & Ehrlich, P. R. (2015). Transformational change: creating a safe operating space for humanity. Ecology and Society, 20(1), art56. doi:10.5751/ES-07181-200156

McCormick, K., Anderberg, S., Coenen, L., & Neij, L. (2013). Advancing sustainable urban transformation. Journal of Cleaner Production, 50, 1–11. doi:10.1016/j.jclepro.2013.01.003

McGinnis, M.D., Ostrom, E. (2014). Social-ecological system framework: initial changes and continuing challenges. Ecol. Soc. 19. doi:10.5751/ES-06387-190230

McLaughlin, J. A., & Jordan, G. B. (2010). Using logic models. In J. S. Wholey, H. P. Hatry, & K. E. Newcomer (Eds.), Handbook of practical program evaluation (3rd ed., pp. 55–88). San Francisco: Jossey-Bass.

Miller, T., Goodling, E., Herrington, C., & Devlin, J. (2015). The Community Watershed Stewardship Program: experiments in engagement and equity in Portland, OR. Current Opinion in Environmental Sustainability, 17, 30–35. doi:10.1016/j.cosust.2015.08.008

Moloney, S., & Horne, R. (2015). Low Carbon Urban Transitioning: From Local Experimentation to Urban Transformation? Sustainability, 7(3), 2437–2453. doi:10.3390/su7032437

Moore, J., Pagani, F., Quayle, M., Robinson, J., Sawada, B., Spiegelman, G., & Van Wynsberghe, R. (2005). Recreating the university from within: Collaborative reflections on the University of British Columbia's engagement with sustainability. International Journal of Sustainability in Higher Education, 6(1), 65–80. doi:10.1108/14676370510573140

Moore, M.-L., Tjornbo, O., Enfors, E., Knapp, C., Hodbod, J., Baggio, J. A., & Norström, A. (2014). Studying the complexity of change: toward an analytical framework for understanding deliberate social-ecological transformations. Ecology and Society, 19(4).

Nevens, F., Frantzeskaki, N., Gorissen, L., & Loorbach, D. (2013). Urban Transition Labs: co-creating transformative action for sustainable cities. Journal of Cleaner Production, 50, 111–122. doi:10.1016/j.jclepro.2012.12.001

Nevens, F., & Roorda, C. (2014). A climate of change: A transition approach for climate neutrality in the city of Ghent (Belgium). Sustainable Cities and Society, 10, 112–121. doi:10.1016/j.scs.2013.06.001

Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. Science, 325(5939), 419–22. doi:10.1126/science.1172133

Ostrom, E. (2007). A diagnostic approach for going beyond panaceas. Proc. Natl. Acad. Sci. U. S. A. 104, 15181–7. doi:10.1073/pnas.0702288104

Ostrom, E., Cox, M. (2010). Moving beyond panaceas: a multi-tiered diagnostic approach for social-ecological analysis. Environ. Conserv. 37, 451–463. doi:10.1017/S0376892910000834

Pahl-Wostl, C. (2007). Transitions towards adaptive management of water facing climate and global change. Water Resources Management, 21(1), 49–62. doi:10.1007/s11269-006-9040-4

Patton, M.Q. (2012). Essentials of utilisation-focused evaluation. Thousand. Oaks, CA: Sage

Parris, T. M., & Kates, R. W. (2003). Characterizing and Measuring Sustainable Development. Annual Review of Environment and Resources, 28(1), 559–586. doi:10.1146/annurev.energy.28.050302.105551

Partelow, S. (2015). Coevolving Ostrom's social–ecological systems (SES) framework and sustainability science: four key co-benefits. Sustain. Sci. doi:10.1007/s11625-015-0351-3

Partelow, S., Boda, C. (2015). A modified diagnostic social-ecological system framework for lobster fisheries: Case implementation and sustainability assessment in Southern California. Ocean Coast. Manag. 114, 204–217. doi:10.1016/j.ocecoaman.2015.06.022

Raven, R., Bosch, S. Van den, & Weterings, R. (2010). Transitions and strategic niche management: towards a competence kit for practitioners. International Journal of Technology Management, 51(1), 57. doi:10.1504/IJTM.2010.033128

Raven, R. P. J. M., Verbong, G. P. J., Schilpzand, W. F., & Witkamp, M. J. (2011). Translation mechanisms in socio-technical niches: a case study of Dutch river management. Technology Analysis & Strategic Management, 23(10), 1063–1078. doi:10.1080/09537325.2011.621305

Regeer, B.J., de Wildt-Liesveld, R., van Mierlo, B., Bunders, J.F.G. (2016). Exploring ways to reconcile accountability and learning in the evaluation of niche experiments. Evaluation 22, 6–28. doi:10.1177/1356389015623659

Robinson, J. (2003). Future subjunctive: backcasting as social learning. Futures 35, 839–856. doi:10.1016/S0016-3287(03)00039-9

Robinson, J., Burch, S., Talwar, S., O'Shea, M., Walsh, M. (2011). Envisioning sustainability: Recent progress in the use of participatory backcasting approaches for sustainability research. Technol. Forecast. Soc. Change 78, 756–768. doi:10.1016/j.techfore.2010.12.006

Rogers, P. J. (2008). Using Programme Theory to Evaluate Complicated and Complex Aspects of Interventions. Evaluation, 14(1), 29–48. doi:10.1177/1356389007084674

Rossi, P. H., Lipsey, W. M., & Freeman, H. E. (2004). Evaluation: A systematic approach. Thousand Oaks: SAGE Publications, Inc.

Rotmans, J. (2005). Societal Innovation: between dream and reality lies complexity. Rotterdam.

Rotmans, J., Loorbach, D. (2009). Complexity and Transition Management. J. Ind. Ecol. 13, 184–196. doi:10.1111/j.1530-9290.2009.00116.x

Ryan, C. (2013). Eco-Acupuncture: designing and facilitating pathways for urban transformation, for a resilient low-carbon future. Journal of Cleaner Production, 50, 189–199. doi:10.1016/j.jclepro.2012.11.029

Schreuer, A., Ornetzeder, M., & Rohracher, H. (2010). Negotiating the local embedding of socio-technical experiments: a case study in fuel cell technology. Technology Analysis & Strategic Management, 22(6), 729–743. doi:10.1080/09537325.2010.496286

Seyfang, G., Longhurst, N. (2016). What influences the diffusion of grassroots innovations for sustainability? Investigating community currency niches. Technol. Anal. Strateg. Manag. 28, 1–23. doi:10.1080/09537325.2015.1063603

Shah, S. H., & Gibson, R. B. (2013). Large dam development in India: sustainability criteria for the assessment of critical river basin infrastructure. International Journal of River Basin Management, 11(1), 33–53. doi:10.1080/15715124.2012.754445

Smith, A. (2007). Translating Sustainabilities between Green Niches and Socio-Technical Regimes. Technology Analysis & Strategic Management, 19(4), 427–450. doi:10.1080/09537320701403334

Smith, A., Raven, R. (2012). What is protective space? Reconsidering niches in transitions to sustainability. Res. Policy 41, 1025–1036. doi:10.1016/j.respol.2011.12.012

Smith, A., Fressoli, M., & Thomas, H. (2014). Grassroots innovation movements: challenges and contributions. Journal of Cleaner Production, 63, 114–124. doi:10.1016/j.jclepro.2012.12.025

Schot, J., Geels, F.W. (2008). Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. Technol. Anal. Strateg. Manag. 20, 537–554. doi:10.1080/09537320802292651

Steffen, W., Richardson, K., Rockstrom, J., Cornell, S. E., Fetzer, I., Bennett, E. M., … Sorlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. Science, 1259855. doi:10.1126/science.1259855

Stuart, J., Collins, P., Alger, M., & Whitelaw, G. (2014). Embracing sustainability: the incorporation of sustainability principles in municipal planning and policy in four mid-sized municipalities in Ontario, Canada. Local Environment, (October), 1–22. doi:10.1080/13549839.2014.936844

Taanman, M. (2014). Looking for transitions. Monitoring approach for sustainable transition programmes. Rotterdam: cpibooks.

Tams, S., & Wadhawan, M. (2012). Innovation Labs: Tackling sustainability through systemic collaboration. The Bath Perspective Magazine, 17, 10–15.

Trencher, G., Bai, X., Evans, J., McCormick, K., & Yarime, M. (2014). University partnerships for co-designing and co-producing urban sustainability. Global Environmental Change, 28, 153–165. doi:10.1016/j.gloenvcha.2014.06.009

Trencher, G., Rosenberg Daneri, D., McCormick, K., Terada, T., Petersen, P., Yarime, M., & Kiss, B. (2016). The role of students in the co-creation of transformational knowledge and sustainability experiments: Experiences from Sweden, Japan and the USA. In W., Filho & L., Brandli (Eds.), Engaging Stakeholders in Education for Sustainable Development at the University Level. Berlin: Springer. doi: 10.1007/978-3-319-26734-0_13

Trencher, G., Terada, T., Yarime, M. (2015). Student participation in the co-creation of knowledge and social experiments for advancing sustainability: experiences from the University of Tokyo. Curr. Opin. Environ. Sustain. 16, 56–63. doi:10.1016/j.cosust.2015.08.001

Trencher, G., Yarime, M., McCormick, K. B., Doll, C. N. H., & Kraines, S. B. (2014). Beyond the third mission: Exploring the emerging university function of co-creation for sustainability. Science and Public Policy, 41(2), 151–179. doi:10.1093/scipol/sct044

Van Buuren, A., & Loorbach, D. (2009). Policy innovation in isolation? Public Management Review, 11(3), 375–392. doi:10.1080/14719030902798289

Van den Bergh, J. C. J. M., Truffer, B., & Kallis, G. (2011). Environmental innovation and societal transitions: Introduction and overview. Environmental Innovation and Societal Transitions, 1(1), 1–23. doi:10.1016/j.eist.2011.04.010

Van den Bosch, S. (2010). Transition Experiments. Exploring societal changes towards sustainability. Erasmus Universiteit Rotterdam.

Van der Laak, W. W. M., Raven, R. P. J. M., & Verbong, G. P. J. (2007). Strategic niche management for biofuels: Analysing past experiments for developing new biofuel policies. Energy Policy, 35(6), 3213–3225. doi:10.1016/j.enpol.2006.11.009

Van Mierlo, B., & Beers, P. J. (2015). Reflexivity and learning in the context of system innovation; Prying loose entangled concepts. In International Sustainability Transition Conference 2015.

van Mierlo, B., B. Regeer et al. (2010). Reflexieve monitoring in actie. Handvatten voor de monitoring van systeeminnovatieprojecten. [Reflexive Monitoring in Action. Guidelines for the monitoring of system innovation projects]. Oisterwijk: Boxpress.

Vandevyvere, H., & Nevens, F. (2015). Lost in Transition or Geared for the S-Curve? An Analysis of Flemish Transition Trajectories with a Focus on Energy Use and Buildings. Sustainability, 7(3), 2415–2436. doi:10.3390/su7032415

Vergragt, P. J., & Brown, H. S. (2007). Sustainable mobility: from technological innovation to societal learning. Journal of Cleaner Production, 15(11-12), 1104–1115. doi:10.1016/j.jclepro.2006.05.020

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. Technology Analysis & Strategic Management, 24(4), 407–420. doi:10.1080/09537325.2012.663964

Vincent, I. V., & Morrison-Saunders, a. (2013). Applying sustainability assessment thinking to a community-governed development: a sea cucumber farm in Madagascar. Impact Assessment and Project Appraisal, 31(3), 208–213. doi:10.1080/14615517.2013.773720

Vogt, J.M., Epstein, G.B., Mincey, S.K., Fischer, B.C., McCord, P. (2015). Putting the “E” in SES: unpacking the ecology in the Ostrom social-ecological system framework. Ecol. Soc. 20, art55. doi:10.5751/ES-07239-200155

Voytenko, Y., McCormick, K., Evans, J., & Schliwa, G. (2015). Urban living labs for sustainability and low carbon cities in Europe: towards a research agenda. Journal of Cleaner Production, 1–10. doi:10.1016/j.jclepro.2015.08.053

Wamsler, C., Luederitz, C., & Brink, E. (2014). Local levers for change: Mainstreaming ecosystem-based adaptation into municipal planning to foster sustainability transitions. Global Environmental Change, 29, 189–201. doi:10.1016/j.gloenvcha.2014.09.008

Westley, F., Antadze, N., Riddell, D. J., Robinson, K., & Geobey, S. (2014). Five Configurations for Scaling Up Social Innovation: Case Examples of Nonprofit Organizations From Canada. The Journal of Applied Behavioral Science, 50(3), 234–260. doi:10.1177/0021886314532945

Westley, F., Olsson, P., Folke, C., Homer-Dixon, T., Vredenburg, H., Loorbach, D., … Leeuw, S. (2011). Tipping Toward Sustainability: Emerging Pathways of Transformation. Ambio, 40(7), 762–780. doi:10.1007/s13280-011-0186-9

Westley, F. R., & Miller, P. (2003). Experiments in Consilience: Integrating Social and Scientific Responses to Biodiversity Conservation Challenges. Island Press.

Wiek, A., & Kay, B. (2015). Learning while transforming: solution-oriented learning for urban sustainability in Phoenix, Arizona. Current Opinion in Environmental Sustainability, 16, 29–36. doi:10.1016/j.cosust.2015.07.001

Wiek, A., Kay, B., & Forrest, N. (2015). Worth the Trouble?! An Evaluative Scheme for Urban Sustainability Transition Labs (USTL) and an Application to the USTL in Phoenix, Arizona. In N. Frantzeskaki, L. Coenen, V. Castan Broto, & D. Loorbach (Eds.), Urban Sustainability Transitions. Routledge.

Wiek, A., Talwar, S., O’Shea, M., & Robinson, J. (2014). Toward a methodological scheme for capturing societal effects of participatory sustainability research. Research Evaluation, 23(2), 117–132. doi:10.1093/reseval/rvt031

Wittmayer, J. M., & Schäpke, N. (2014). Action, research and participation: roles of researchers in sustainability transitions. Sustainability Science, 483–496. doi:10.1007/s11625-014-0258-4

Wittmayer, J. M., Schäpke, N., van Steenbergen, F., & Omann, I. (2014). Making sense of sustainability transitions locally: how action research contributes to addressing societal challenges. Critical Policy Studies, 8(4), 465–485. doi:10.1080/19460171.2014.957336

Yin, R. K. (2009). Case Study Research: Design and Methods (4th ed.). Thousand Oaks: Sage Publications.

Supplementary Material A

Table 1 presents an exemplary subset of the literature that was pooled and selected as part of the literature review. In total, 61 unique case studies were used for developing the tentative evaluative scheme for sustainability transition experiments. The reviewed literature can be categorized according to seven sustainability laboratories, including (urban) transition labs, socio-technical experiments, (urban) living labs, homelabs, campus as laboratory, social innovation labs, and urban sustainability transition labs. The whole body of literature we draw on for developing each evaluative feature is referenced in Section 3 of the present article.

Table 1: Overview of different Sustainability Transition Laboratories

Sustainability Transition Laboratory	Focus	Underlying Concepts	Exemplary Literature
(Urban) Transition Labs	Various	Transition Management; organizational learning; action research; transdisciplinary	Farrelly and Brown, 2011; Loorbach and Rotmans, 2010; Nevens et al., 2013; Wittmayer et al., 2014
Socio-Technical Experiments	Innovation mainstreaming	Strategic niche management; innovation studies; organizational learning; product service systems; transition management	Brown et al., 2003; Ceschin, 2014; Quist et al., 2011; Schreuer et al., 2010; Vergragt and Brown, 2012
(Urban) Living Labs	Industry and research institutes	Product service systems; transdisciplinary research; action research; innovation studies	Audet and Guyonnaud, 2013; Evans and Karvonen, 2014; McCormick and Kiss, 2015; Ryan, 2013; Voytenko et al., 2015
HomeLabs	Everyday practices	Practice-oriented participatory; second-order learning; organizational learning	Davies and Doyle, 2015; Davies et al., 2012; Laakso and Lettenmeier, 2015; Liedtke et al., 2015
Campus as Laboratory	Universities	Community-based action research; transdisciplinary research; organizational learning	Abbott, 2014; Hart et al., 2015; Lang and Wiek, 2013; Robinson et al., 2013; Rojas et al., 2007
Social Innovation Labs	Grassroots movements, communities	Networks of transformational agency; changes in everyday life	Avelino et al., 2014; Seyfang and Longhurst, 2015; Smith et al., 2015; Westely et al., 2014
Urban Sustainability Transition Labs	Urban environments	Transformational sustainability research; transdisciplinary research; intervention studies	Bernstein et al., 2014; Forrest and Wiek, 2015; Wiek and Kay, 2015; Wiek et al., 2015, 2012

References

Abbott, A., 2014. The university experiment: Campus as laboratory. Nature 514, 288–91. doi:10.1038/514288a

Audet, R., Guyonnaud, M.-F., 2013. Transition in practice and action in research. A French case study in piloting eco-innovations. Innov. Eur. J. Soc. Sci. Res. 26, 398–415. doi:10.1080/13511610.2013.850019

Avelino, F., Wittmayer, J., Haxeltine, A., Kemp, R., O'Riordan, T., Weaver, P., Loorbach, D., Rotmans, J., 2014. Game Changers and Transformative Social Innovation. The Case of the Economic Crisis and the New Economy, TRANSIT working paper, TRANSIT: EU SSH.2013.3.2-1 Grant agreement no: 613169.

Bernstein, M.J., Wiek, A., Brundiers, K., Pearson, K., Minowitz, A., Kay, B., Golub, A., 2014. Mitigating urban sprawl effects: a collaborative tree and shade intervention in Phoenix, Arizona, USA. Local Environ. 1–18. doi:10.1080/13549839.2014.965672

Brown, H.S., Vergragt, P., Green, K., Berchicci, L., 2003. Learning for Sustainability Transition through Bounded Socio-technical Experiments in Personal Mobility. Technol. Anal. Strateg. Manag. 15, 291–315. doi:10.1080/09537320310001601496

Ceschin, F., 2014. How the Design of Socio-technical Experiments Can Enable Radical Changes for Sustainability. Int. J. Des. 8, 1–21.

Davies, A.R., Doyle, R., 2015. Transforming Household Consumption: From Backcasting to HomeLabs Experiments. Ann. Assoc. Am. Geogr. 105, 425–436. doi:10.1080/00045608.2014.1000948

Davies, A.R., Doyle, R., Pape, J., 2012. Future visioning for sustainable household practices: spaces for sustainability learning? Area 44, 54–60. doi:10.1111/j.1475-4762.2011.01054.x

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 Reg. Res. 38, 413–430. doi:10.1111/1468-2427.12077

Farrelly, M., Brown, R., 2011. Rethinking urban water management: Experimentation as a way forward? Glob. Environ. Chang. 21, 721–732. doi:10.1016/j.gloenvcha.2011.01.007

Forrest, N., Wiek, A., 2015. Success factors and strategies for sustainability transitions of small-scale communities – Evidence from a cross-case analysis. Environ. Innov. Soc. Transitions 1–19. doi:10.1016/j.eist.2015.05.005

Hart, D.D., Bell, K.P., Lindenfeld, L.A., Jain, S., Johnson, T.R., Ranco, D., McGill, B., 2015. Strengthening the role of universities in addressing sustainability challenges: the Mitchell Center for Sustainability Solutions as an institutional experiment. Ecol. Soc. 20, art4. doi:10.5751/ES-07283-200204

Laakso, S., Lettenmeier, M., 2015. Household-level transition methodology towards sustainable material footprints. J. Clean. Prod. 1–8. doi:10.1016/j.jclepro.2015.03.009

Lang, D.J., Wiek, A., 2013. The role of universities in fostering urban and regional sustainability, in: Mieg, H.A., Töpfer, K. (Eds.), Institutional and Social Innovation for Sustainable Development. Routledge, London, pp. 394–411.

Liedtke, C., Baedeker, C., Hasselkuß, M., Rohn, H., Grinewitschus, V., 2015. User-integrated innovation in Sustainable LivingLabs: an experimental infrastructure for researching and developing sustainable product service systems. J. Clean. Prod. 97, 106–116. doi:10.1016/j.jclepro.2014.04.070

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

McCormick, K., Kiss, B., 2015. Learning through renovations for urban sustainability: the case of the Malmö Innovation Platform. Curr. Opin. Environ. Sustain. 16, 44–50. doi:10.1016/j.cosust.2015.06.011

Nevens, F., Frantzeskaki, N., Gorissen, L., Loorbach, D., 2013. Urban Transition Labs: co-creating transformative action for sustainable cities. J. Clean. Prod. 50, 111–122. doi:10.1016/j.jclepro.2012.12.001

Quist, J., Thissen, W., Vergragt, P.J., 2011. The impact and spin-off of participatory backcasting: From vision to niche. Technol. Forecast. Soc. Change 78, 883–897. doi:10.1016/j.techfore.2011.01.011

Robinson, J., Berkhout, T., Cayuela, A., Campbell, A., 2013. Next Generation Sustainability at The University of British Columbia: The University as Societal Test-Bed for Sustainability, in: Koenig, A. (Ed.), Regenerative Sustainable Development of Universities and Cities: The Role of Living Laboratories. Edward Elgar, Cheltenham.

Rojas, A., Richer, L., Wagner, J., 2007. University of British Columbia Food System Project: Towards Sustainable and Secure Campus Food Systems. Ecohealth 4, 86–94. doi:10.1007/s10393-006-0081-1

Ryan, C., 2013. Eco-Acupuncture: designing and facilitating pathways for urban transformation, for a resilient low-carbon future. J. Clean. Prod. 50, 189–199. doi:10.1016/j.jclepro.2012.11.029

Schreuer, A., Ornetzeder, M., Rohracher, H., 2010. Negotiating the local embedding of socio-technical experiments: a case study in fuel cell technology. Technol. Anal. Strateg. Manag. 22, 729–743. doi:10.1080/09537325.2010.496286

Seyfang, G., Longhurst, N., 2015. What influences the diffusion of grassroots innovations for sustainability? Investigating community currency niches. Technol. Anal. Strateg. Manag. 7325, 1–23. doi:10.1080/09537325.2015.1063603

Smith, A., Hargreaves, T., Hielscher, S., Martiskainen, M., Seyfang, G., 2015. Making the most of community energies: Three perspectives on grassroots innovation. Environ. Plan. A. doi:10.1177/0308518X15597908

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. Technol. Anal. Strateg. Manag. 24, 407–420. doi:10.1080/09537325.2012.663964

Voytenko, Y., McCormick, K., Evans, J., Schliwa, G., 2015. Urban living labs for sustainability and low carbon cities in Europe: towards a research agenda. J. Clean. Prod. 1–10. doi:10.1016/j.jclepro.2015.08.053

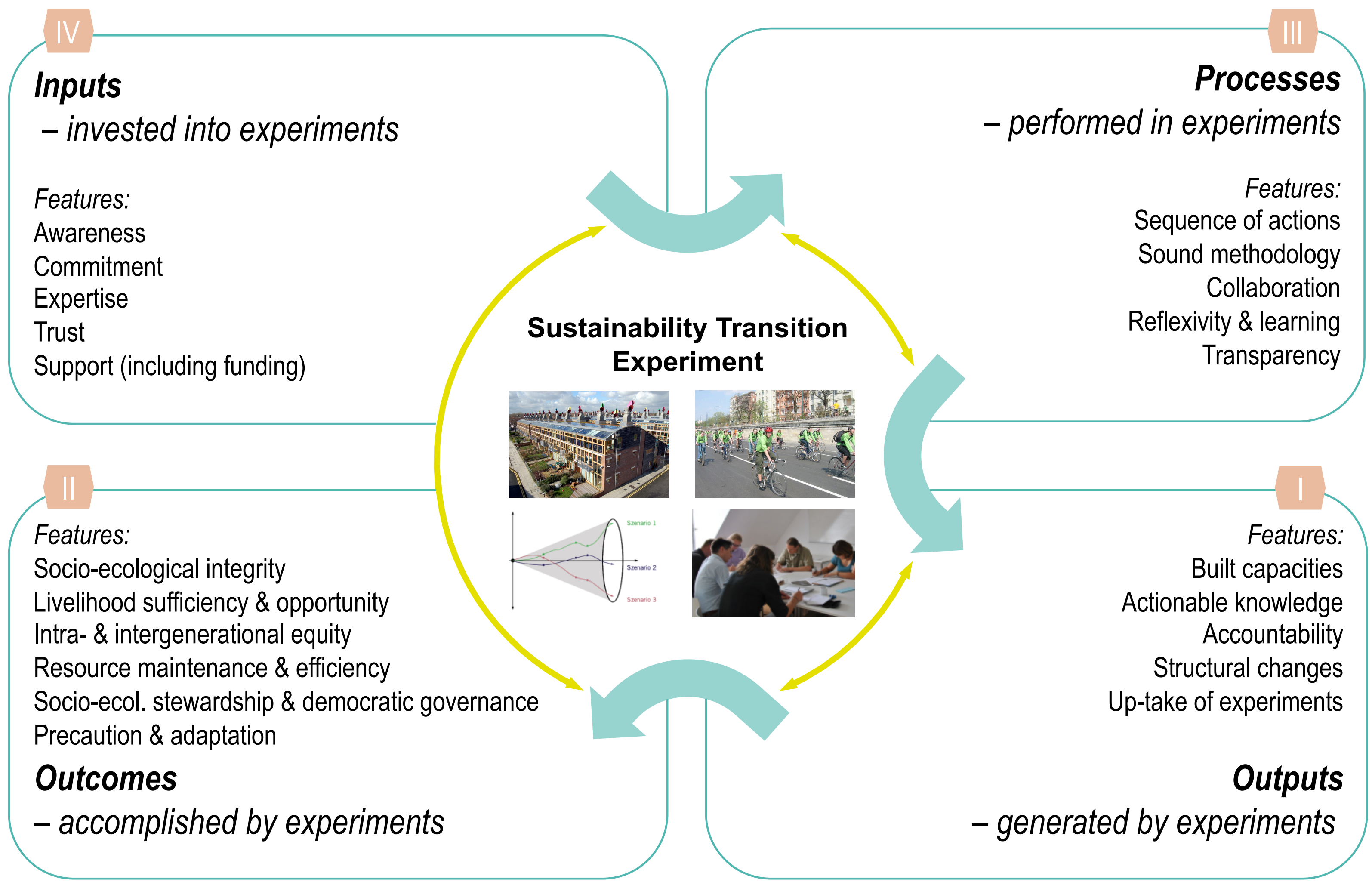
Westley, F., Antadze, N., Riddell, D.J., Robinson, K., Geobey, S., 2014. Five Configurations for Scaling Up Social Innovation: Case Examples of Nonprofit Organizations From Canada. J. Appl. Behav. Sci. 50, 234–260. doi:10.1177/0021886314532945

Wiek, A., Kay, B., 2015. Learning while transforming: solution-oriented learning for urban sustainability in Phoenix, Arizona. Curr. Opin. Environ. Sustain. 16, 29–36. doi:10.1016/j.cosust.2015.07.001

Wiek, A., Kay, B., Forrest, N., 2015. Worth the Trouble?! An Evaluative Scheme for Urban Sustainability Transition Labs (USTL) and an Application to the USTL in Phoenix, Arizona, in: Frantzeskaki, N., Coenen, L., Castan Broto, V., Loorbach, D. (Eds.), Urban Sustainability Transitions. Routledge.

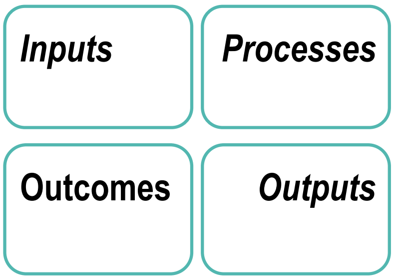
Wiek, A., Ness, B., Schweizer-Ries, P., Brand, F.S., Farioli, F., 2012. From complex systems analysis to transformational change: a comparative appraisal of sustainability science projects. Sustain. Sci. 7, 5–24. doi:10.1007/s11625-011-0148-y

Wittmayer, J.M., 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. doi:10.1080/19460171.2014.957336

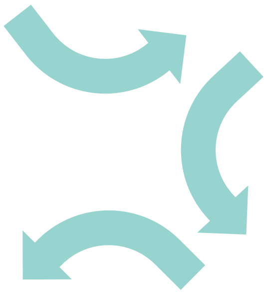


IV
Inputs
– invested into experiments
Features:
Awareness
Commitment
Expertise
Trust
Support (including funding)
III
Processes
– performed in experiments
Features:
Sequence of actions
Sound methodology
Collaboration
Reflexivity & learning
Transparency
Sustainability Transition Experiment
Szenario 1
Szenario 2
Szenario 3
II
Features:
Socio-ecological integrity
Livelihood sufficiency & opportunity
Intra- & intergenerational equity
Resource maintenance & efficiency
Socio-ecol. stewardship & democratic governance
Precaution & adaptation
Outcomes
– accomplished by experiments
I
Features:
Built capacities
Actionable knowledge
Accountability
Structural changes
Up-take of experiments
Outputs
– generated by experiments

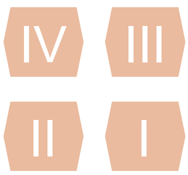
Legend



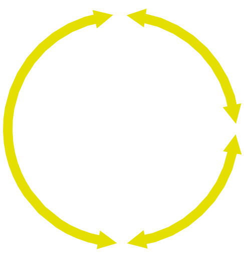
The four dimension of the basic logic model of evaluation adopted for sustainability transition experiments. Depict as parallel and interdependent, evaluation requires iterations among the four dimensions.



Following a sequential order from inputs to outcomes, the arrows display the ideal-typical sequence of activities for designing sustainability transition experiments.



The numbering indicates the sequence of applying the evaluative dimensions following the evaluation rationale



The yellow arrows indicate the inter-connectedness of the steps and potential iterations in an experiment.

Highlights:

- A tentative scheme is presented to evaluate sustainability transition experiments
- The scheme is applicable to different types of sustainability transition experiments
- The scheme comprehensively captures the outcomes, inputs and mediating attributes
- It is ready to be applied including guidance for specifying it to particular cases
- It supports experiments in becoming more effective and efficient via reflection and learning