Environmental Science and Policy 103 (2020) 58–66

Contents lists available at ScienceDirect

Environmental Science and Policy

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

Measuring sustainability: An evaluation framework for sustainability transition experiments

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ARTICLE INFO

Keywords:
Sustainability transition experiments
Transition impact assessment
Societal effects
Sustainability transition impacts
Transdisciplinary research evaluation

ABSTRACT

Sustainability Transition Experiments (STEs), leveraging a transdisciplinary research approach, have recently been proposed as a method to accelerate sustainability transitions. This paper outlines a proposed three-part evaluation framework to assess the process, societal effects, and sustainability transition impacts of STEs. The paper extracts the key insights from multiple literatures, generating a set of indicators to be used in assessing sustainability transition experiments. Particular emphasis is placed on the assessment of longer-term sustainability impacts. We propose a development pathway approach to organize elements of sustainability transition impact into a coherent framework that highlights the inter-relationships between levels of scales in systems transition and foregrounds the role of changes in governance roles and relationships and the role of politics in transitions. The paper offers insights into the challenge of evaluating the sustainability transition impacts of a transdisciplinary research project and provides an important bridge between the evaluation of processes, societal effects, and their link to sustainability transition impacts.

1. Introduction

Fostering sustainability transition is a pressing global societal challenge. Socio-technical approaches characterize transitions as

> major, long-term technological changes in the way societal functions are fulfilled. Technological transitions do not only involve changes in technology, but also changes in user practices, regulation, industrial networks, infrastructure, and symbolic meaning or culture (Geels, 2002, p. 1257).

Sustainability Transition Experiments (STEs) leveraging a transdisciplinary research approach have recently been proposed as a method to accelerate such sustainability transitions (Wiek et al., 2014; Schäpke et al., 2018a,b). However, there is a presumption in the literature and by practitioners that STEs will lead, as a result of societal effects, to sustainability transition. We need methods by which to evaluate this causal claim, to understand what is happening within transition processes, and to provide insight, not just to researchers, but also to STE designers and facilitators as to the efficacy of their processes.

There have long been collaborative projects between citizens and local governments focused on sustainability issues but we focus here on STEs which are "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" (Luederitz et al., 2016, p. 1). Transition experiments may be focused on low-carbon outcomes (Rosenbloom et al. 2018), energy (Grübler, 2012), climate governance (Turnheim et al., 2018), or the urban context (Schäpke et al., 2018a). Cherp et al. note that "'sustainability' transitions may also include changes in food systems, distribution of wealth, human rights, governance and conflicts" (2018, p. 176). STEs commonly focus on experimentation, innovation, and learning and represent a new form of collaboration to foster sustainability transition (Loorbach et al., 2017).

Evaluating sustainability transition experiments poses several challenges beyond those of evaluating sustainability projects such as public awareness campaigns, home retrofit programs, or deployment of renewable energy technologies. As numerous authors have pointed out, transitions are inherently boundary-spanning and affect multiple domains (e.g. social, political, cultural and technical) (Hölscher et al., 2017). Developing tools and methods to capture change across such wide-ranging domains is difficult both conceptually and practically. In addition, transitions occur within complex systems which implies interdependence between system elements, emergent phenomena that

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https://doi.org/10.1016/j.envsci.2019.10.012
Received 15 April 2019; Received in revised form 8 October 2019; Accepted 16 October 2019
Available online 06 November 2019
1462-9011/

Table 1
Process Evaluation Categories (See Supplement 1 for further detail and sources).

Category	Elements
Inputs	Design and facilitation capacity, funding and partners, participant motivations
External context	Political, social, economic context
Enabling conditions	Inclusivity, fairness, transparency, trust
Methods	Iterative, reflexivity, dialogue, negotiation, collective problem solving
Supporting Transition	Niche/regime interaction, aligning innovations, experimentation and learning, conceptualizing sustainability
Scope	Scope of process adequately broad
Governance	Stakeholder capacities, power relations, engaging future and non-human actors, recognition

cannot be predicted a priori, and discontinuous or non-linear effects of systems interventions (Andersson, 2014; Westley et al., 2011). Arnold et al. note, "complexity introduces a big problem for theory-based intervention design and evaluation: since the system involved changes its characteristics over time, the intervention logic and its components do not necessarily remain stable" (2018, p. 17).

Not only do such changes pose significant attribution challenges, system transitions tend to take place over long time periods (Schot and Kanger, 2018). Capturing the long-term contribution of an intervention that runs for a period of months or even years is very difficult; even more so given that, due to finite resources, evaluations will usually focus on only part of an STE lifecycle. Finally, there is a tension between the need for evaluation that generates learning for those designing and managing sustainability transition experiments and evaluation to provide accountability for 'results' driven by funders and governments. A finding of "'we had a good process and learnt things' does little to address the need for accountability in government interventions" (Arnold et al., 2018, p. 39). This tension is especially acute for low-carbon and sustainability transition experiments that have a specific goal of, for example, reducing GHG emissions in a given sector, geographic area, or target population due to short-term funding and reporting requirements (Rosenbloom et al., 2018, Potvin et al., 2018).

Despite these challenges, it is crucial to evaluate STEs in order to evaluate their actual effects and consequences. We need methods that will enable us to understand what is happening within transition processes, and to provide insight to STE designers and facilitators as to the efficacy of their processes. Although transitions take time, are boundary-spanning, and take place within complex systems, transitions work is happening now – and needs to happen now – and evaluation of STEs can support and guide this work. This leads to the research question we explore in this paper: How can we conceptualize, and evaluate, the contributions to sustainability transitions of STEs? We note that while the focus of this paper is on assessing STEs, we believe the framework developed here may also be applied in other domains as well as to projects operating at different scales.

1.1. Evaluating sustainability transition experiments

Evaluating transdisciplinary research *processes* is a necessary component of the evaluation framework as a key element of STEs is engaging stakeholders and how that is done matters. In addition, several literatures point to the link between process and outcomes, i.e. the design and execution of a process influences the kinds and qualities of outcomes expected. Evaluating societal *effects* captures the short-term outputs and medium-term outcomes of an STE that, presumably, will lead to sustainability transitions. However, these societal effects do not capture such sustainability transition *impacts*. As a result, in order to support STE evaluation efforts, we propose a tripartite evaluation framework that examines STE processes, societal effects, and sustainability transitions impacts. The first two parts, discussed in this section, build on existing evaluation literatures, while the third requires development of a new framework, and will be discussed in a separate section.

1.2. Process evaluation

Transition experiments are participatory by nature (Frantzeskaki and Loorbach, 2012; Luederitz et al., 2016; Schäpke et al., 2018a). Labs, transition arenas, low-carbon, and sustainability transition experiments all have elements where multiple stakeholders are engaged in transition processes (Schäpke et al., 2018b). A fruitful start for our investigation was the literature on evaluation of participatory processes for insights into evaluating sustainability transition experiments. These evaluations tend to focus on either the design and procedural elements of the process itself or on the outcomes of the process. Procedural evaluation looks at whether processes are inclusive, fair, and present unbiased information (Abelson et al., 2003; Black et al., 2008). Rowe and Frewer (2005), following Ableson et al. (2003), propose a framework of fairness and competence/efficiency to measure the effectiveness of public engagement processes. Fairness is a measure of perception - do participants (and the wider public) believe the exercise was designed and conducted in a fair and representative manner. However, Rowe and Frewer extend the definition of competence to include how efficient the information flow is and how well that information is processed (i.e. into policy or other outcomes and objectives).

STEs are also characterized by a strong reliance on the transdisciplinary co-production of knowledge and co-creation of research projects (Pregernig et al., 2018; Schäpke et al., 2018a, 2017). There has been important work done on the evaluation of co-production processes themselves (e.g. understandings of co-production, roles of participants collaboratively developing research objectives and questions), recommendations for successful projects (Hansson and Polk, 2017) and the extent to which evaluations themselves are co-developed (Wanner et al., 2018). This literature points to the need for co-production processes to be iterative, interactive and reflexive, provide transparent discourse and collaboration, and embed broad and diverse participation and engagement. Note that co-production approaches also have implications for societal effects evaluation. Table 1 below presents the Process evaluation level of our framework.[2]

1.3. Societal effects evaluation

Outcome evaluation in the participatory process literature looks at both impact of the process on participants (e.g. in terms of increased knowledge or level of civic participation), on the products of the process (e.g. reports) and the use of those products by decision makers (Barrett et al., 2012; Gaventa and Barrett, 2010). However, sustainability transition experiments are often started outside of government and may seek to disrupt, rather than engage with, existing governance. It is therefore important to extend the analysis beyond effects on policy-making processes. Schäpke et al. (2017) discuss the importance of social learning effects in transition processes and the literature on co-production of knowledge provides insights on how to capture these learning effects. As Walter et al. (2007) point out, there is a strong

[2] See Supplement 1 for a full elaboration of the Process level of our evaluation framework.

Table 2
Societal Effects Evaluation Categories (See Supplement 2 for further detail and sources).

Category	Elements
Individual Capacity	Understanding and learning, agency and empowerment, reflexivity on role in transition, changed or broadened perceptions
Usable Products	Innovative technologies or social innovations, action plans, media, publications, written reports and research
Networks and Relationships	Expanded and strengthened networks, sharing with networks, development of social capital
Institutional change – Policy	Direct and indirect policy influence, new evidence/information introduced to policymakers
Institutional change – Organizational	Shifts in organizational roles, responsibilities or rules of engagement between stakeholders, shifts in investment strategies, changes in organizational decision making processes and governance
Climate/Energy Effects	Carbon emissions reductions or other sustainability effects such as reduced energy demand, increased renewable energy supply, increases in energy efficiency

correlation between outcomes and "involvement as measured by the number of engagement activities that took place during the project" however more research needs to be done in order to draw strong causal links between the process elements of a given experiment and outcomes.

Wiek et al. (2014); Cornish (2013), and others have extended the literature on the impact of participatory sustainability projects (Talwar et al., 2011; Walter et al., 2007) to encompass the societal effects of such projects. The Wiek et al. (2014) framework categorizes societal effects into first-order effects which are the direct outcomes and outputs of a project (the short term "splash" from a specific event or process) such as enhanced capacity, networks and usable products (e.g. action plans, reports, web sites, new technologies) and second-order effects ("the ripples" which are consequences of first order effects) such as institutional changes (e.g. new policies, organizational changes), decisions and actions. Wiek et al.'s approach broadened the categories of effect from previous work in the field by including structural changes as potential outcomes. The framework they proposed acknowledges the challenges of attributing effects due to time delays between processes of deliberation or other events that have occurred and their effects, and to the difference between first-order and second-order effects. However, the definitions and indicators of second-order structural effects are not precise, for example conflating societal shifts such as norms and behaviour change with policy and institutional effects. These are very different types of effects which should be separately evaluated. Scholz and Steiner (2015b, p. 539, 2015a) contend that "it is not the decisions and actions but rather the new knowledge which is integrated in processes of mutual learning and consented orientations for making sustainable decisions that is the main outcome of a transdisciplinary process." This conception maps to first and second order effects described above but does not address sustainability-specific outcomes nor impacts.

Luederitz et al. (2016) attempt to measure impacts of sustainability transition experiments by asking whether the experiment strengthened socio-ecological integrity, enhanced livelihood sufficiency and opportunity and other measures of sustainability. However, this framing is evaluating specific interventions not the aggregate portfolio of experiments that are part of many STEs. This leads the framework to underrepresent the importance of mutual reinforcement dynamics between experiments (Grin, 2011; Riddell, 2015) and where the STE fits into a broader set – or ecology – of processes (Chilvers & Kearnes, 2016). In addition, this framework does not address how a given process is contributing to a sustainability *transition* which is different from evaluating specific indicators of sustainability. Lang et al. (2012) describe as outcomes the (re)-integration of knowledge to further societal and scientific practice. While referencing measures such as a "correlation between project involvement and increased decision-making capacity" (p. 39), the authors do not elaborate on a link between such outcomes and sustainability transition. Table 2 below elaborates the Societal Effects categories of our framework.[3] Note that while this framework was developed for projects focussed on climate change and energy, the framework can be generalized to include other ecological effects.

Societal effects evaluation gives us important information on the short-term outputs and medium-term outcomes of sustainability transition experiments. However, these approaches do not explicitly address the issue of societal transition; instead they typically assume these impacts will happen as a result of societal effects. For example, Hansson & Polk note that "transdisciplinary co-production approaches are built on the assumption that the intermediate or direct effects of participatory research contribute indirectly to transformational societal change" (2017, p. 134). In the same paper, the authors conclude that "there are no clear mechanisms that link participatory features to impact; there is instead a complex web of relationships, institutional cultures, and political agendas that require that we open up the categories to see how they are conceived of by different actors internal as well as external to the project" (p. 141). The literature on societal effects is also vague on how 'transformational societal change' is to be conceptualized, not to mention how to assess the contribution of an STE to such change, what we describe as Sustainability Transition Impacts in the following section.

2. Sustainability transition impacts and development pathways

We propose a development pathway approach as a framework with which to characterize transformational societal change and a means to capture contributions of an STE. A development path was defined in the IPCC Fourth Assessment Report as the "complex array of technological, economic, social, institutional, cultural and biophysical characteristics that determines the interactions between human and natural systems, including consumption and production patterns, over time at a particular scale" (Sathaye et al., 2007, p. 700) while Smith et al. (2010) describe a "dynamic array of reinforcing principles, values, materialities, and collective projects that steer development" (Moore et al., 2018) and intersect in many ways (Rosenbloom, 2017). As Burch et al. (2014) point out, the IPCC definition is quite broad and does not move us very close to being able to conceptualize sustainability transition impacts. To address this issue, they integrate theories of socio-technical transition with multi-level governance (MLG) theory. A commonality of socio-technical approaches is a focus on the inter-connected nature of socio-technical change. As Wilson and Grubler note, "technologies and their institutional settings co-evolve. Change in these different areas is mutually dependent, mutually enhancing and mutually dampening" (2011, p. 165).

The dominant conceptual framing in the transitions literature is the multi-level perspective (MLP) which describes the inter-relationships between the levels of niche, regime, and landscape (Geels, 2011; Smith et al., 2010). The MLP posits that changes in socio-technical systems arise mainly from the intersection of two processes. One occurs when collections of niche innovations align to put pressure on the policy regime, and the second when landscape level changes (e.g. economic pressures) create windows of opportunity within the regime for niche innovations to take hold. On the other hand, the MLG literature focuses on governance processes and "theorizes the reallocation of authority

[3] See Supplement 2 for a full elaboration of the Societal Effects level of our evaluation framework.

away from the central state to regional authorities, non-state actors, and even cross-boundary networks" (Burch et al., 2014, p. 470). This integration is highly relevant for conceptualizing sustainability transition impacts as it highlights the inter-relationships between levels of scales in systems transition and also foregrounds the role of changes in governance roles and relationships highlighted by scholars such as Grin et al. (2010) and Kenis et al. (2016) and the role of politics in transitions (Meadowcroft, 2009).

Combining socio-technical systems and MLG approaches, Burch et al. (2014) argue that development paths

> "operate at the scale of socio-technical systems and systems of governance, which consist of social systems (formal and informal rules, habits, and norms), networks amongst actors, diverse technologies, and ecological systems; [are] an emergent property of a system, imbued with values, norms, rules, and habits rather than a measurable set of conditions/characteristics; [exhibit] a particular set of interlinking regime rules and behaviours, including inertia and cascading effects over time; and [are] reinforced at multiple levels, with varied capacities and constraints on local agency occurring at each level" (Burch et al., 2014, p. 471).

Moore et al. build on this approach, arguing that a development path "is a driver of change (linear, nonlinear, and emergent) in inextricably coupled ecological and social systems" (2018, p. 13), in effect encapsulating the regime and landscape concepts from MLP. This focus on linked social and ecological systems is helpful in ensuring that sustainability transition is broadly framed. However, these treatments of development pathways leave open three key questions: how do we know which development pathway we are on? How do we know whether development path change is happening? And, how do we know whether any such change is moving in a more sustainable direction?

2.1. Understanding the pathway we are on

The implication of the wide definition of development pathways discussed here is that all interconnecting and interdependent elements of a complex socio-technical-natural system need to be considered. While it may be possible to characterize constituent elements of a development pathway, complex systems are by their very nature emergent and not reducible to a discrete list of component parts. However, we would suggest that rising GHG emissions, social and economic inequality, and global environmental degradation consequences are all indicators of an unsustainable pathway. In the words of the recently released Global Environmental Outlook 6 report from the United Nations Environment Program:

> Unsustainable production and consumption patterns and trends as well as inequality, combined with population growth-driven increase in resource use, put at risk the healthy planet needed to attain sustainable development. These trends are deteriorating planetary health at unprecedented rates with increasingly serious consequences especially for poorer people and regions (UNEP, 2019, p. 2)

How then might we conceptualize changes to this unsustainable pathway? We suggest that five characteristics of development pathways provide a framework with which to categorize sustainability transition elements and the changes that occur within them (see Table 3). In the following section we elaborate on each of these characteristics (adapted from Burch et al., 2014; Moore et al., 2018, and literatures cited in following section) in order to better understand development pathway change.

2.2. Understanding development pathway change

The five characteristics here emerge from the development pathways literature along with integration from transitions, environmental justice, and transformations literatures. Within each characteristic, we propose categories of impacts. These categories draw on multiple literatures such as transition theory, environmental justice, social practice, and transformations. Each of these literatures speaks to a component of development pathway change. The development pathway framing provides a useful way to integrate these different literatures and illuminate different dimensions of sustainability transition impacts.

2.2.1. Socio-technical systems and governance

The socio-technical systems and governance characteristic includes the elements of changes in governance roles and relationships (Loorbach and Rotmans, 2010; Stirling, 2014) along with reduced barriers to transition such as institutional inertia and built infrastructure (Burch et al., 2014; Geels, 2018). Capturing how an STE is contributing to the reduction of structural and institutional barriers to transition, and whether those barriers are in fact being reduced, is an important measure of sustainability transition impact.

2.2.2. Interlinking regime rules and behaviours

Changes in values and norms represent emergent properties of a system and are captured by assessing regime and collective practices. Changes in regime rules and behaviours are represented by changes in regime routines and practices including justice elements such as contribution to the equitable distribution of costs and benefits of transition (Silveira and Pritchard, 2018; Walker, 2012; Williams and Doyon, 2019) and "normalization" of sustainability embedded within institutions (Shove and Walker, 2010).

2.2.3. Reinforcement at multiple levels

Assessing niche-landscape alignment surfaces both how an STE is aligning to changing social, cultural, or political trends and how an STE might be *influencing* those trends (Geels, 2002; Geels and Schot, 2007). In addition, the transformations literature highlights the importance of multi-scale effects of systems transition (Asquith et al., 2018; O'Brien and Sygna, 2013).

2.2.4. Actors and practices

The embedding of sustainable behaviours in practice, routine, and cultural norms in both regime institutions and public collectives is a crucial element of sustainability transition. Changes in values and norms as embodied by collective practice represent emergent properties of a system and are captured by assessing collective practices change (Moore et al., 2018; O'Brien et al., 2018) and the examination of actors roles, relationships, and agency (Avelino and Wittmayer, 2017; Schot, 2017).

2.2.5. Social and ecological systems

Finally, the concept of a driver of change in linked social and ecological systems captures impacts beyond climate/energy effects of the type highlighted in the transformations literature. For example, large-scale societal change processes involving socio-ecological interactions (Hölscher et al., 2017), reducing "risk and vulnerability while protecting the viability and integrity of the atmosphere, biosphere, hydrosphere and cryosphere to support the well-being of species, including humans, both now and in the future" (O'Brien and Sygna (2015), and "a range of desirable responses that are considered necessary to meet the broader challenges of global sustainability, including the targets established under the United Nations Sustainable Development Goals (SDGs)" (O'Brien et al., 2018, p. 28).

Collectively, these five characteristics support a broad set of indicators that capture elements of development pathway change. However, in the context of sustainability transition impacts, we are interested in not just change, but in change that is moving in a more sustainable direction. In the development pathways literature conceptions of sustainability, Burch et al. highlight "the desirability of integrating climate policy with broader sustainability goals relating to

Table 3
Five characteristics of development pathways.

Characteristic	Description
Socio-technical systems and governance (Burch et al., 2014)	Governance roles and relationships (Loorbach and Rotmans, 2010; Silveira and Pritchard, 2018) Institutional and structural barriers to transition (Geels, 2018a; Moser & Ekstrom, 2010; Burch et al., 2014)
Interlinking regime rules and behaviours (Burch et al., 2014)	Regime rules, behaviours, routines and practices (Walker, 2012; Silveira and Pritchard, 2018; Shove and Walker, 2010)
Reinforcement at multiple levels (Burch et al., 2014)	Niche-regime, niche-landscape, landscape-regime interactions (Geels, 2002; Geels and Schot, 2007) and multi-scale effects of system transition (Folke et al., 2010; O'Brien and Sygna, 2013)
Actors and practice (Moore et al., 2018)	Actor roles, relationships and agency (Schot, 2017; Avelino and Wittmayer, 2017) Collective values and norms embodied in practice (Moore et al., 2018; O'Brien et al., 2018)
Social and ecological systems (Burch et al., 2014; Moore, et al., 2018)	Sustainability in multiple dimensions Inter-connected, and interdependent systems (Moore et al., 2018; O'Brien & Sygna, 2015; O'Brien et al., 2018; Burch et al., 2014)

economics, social dimensions, technology, and environment" (Burch et al., 2014, p. 473; cf. Robinson et al., 2006). The UN Sustainable Development Goals (United Nations, 2019) provide a mechanism through which to assess the comprehensiveness of the conceptions of sustainability in transition impacts. Sustainability is here represented by 17 integrated and interrelated Sustainable Development Goals, emphasising the three well-known dimensions of sustainable development: the social, the economic and the environmental. While the SDGs have been critiqued for its perceived top-down approach to governance (Bowen et al., 2017; Hajer et al., 2015), difficulty in translating goals to measurable actions (Biermann et al., 2017; Kanter et al., 2016), and the lack of capacity of developing nations and non-state actors to address the SDGs (El-Zein et al., 2016), they are generally recognized across institutions and national governments, and provide a comprehensive set of goals across the dimensions of social, economic, and environmental sustainability. We use the SDGs to assess the direction and comprehensiveness of development path change in our proposed evaluation framework.

When they are used in this way, mapping the SDGs to our proposed evaluation categories becomes a way of undertaking a gap analysis to assess whether there are elements of sustainability transition that are missing in the framework. In doing this mapping, it becomes clear that the sustainability transitions impacts framework proposed here does have the capacity to reflect all of the SDGs. For example, the 'justice' category in our proposed evaluation framework notes the importance of capturing the equitable costs and benefits of transition (cf. Walker, 2012; Silveira and Pritchard, 2018). The SDGs provide specific areas where this equity should be found (for example reducing poverty everywhere (Goal 1), healthy lives and well-being for all (3), inclusive economic growth and decent work for all (8), and reducing inequality within and among countries (10)). Goal 16 explicitly refers to the promotion of peaceful and inclusive societies with access to justice for all. On the other hand, a key element of environmental justice – recognition of the historical (and current) marginalization of peoples (e.g. Indigenous peoples in Canada) – is not explicitly mentioned in the SDGs. In this case, our proposed evaluation framework extends and deepens the SDG conceptualization of sustainability and justice.

It is perhaps in the category of 'social and ecological systems' that the SDGs provide the most benefit in elaborating details of sustainability transition impacts. Burch et al. (2014), O'Brien & Sygna (2015), O'Brien et al. (2018), and Moore et al. (2018) all highlight the importance of impacts on linked socio-ecological systems in transition. The SDGs provide a comprehensive set of areas through which to assess these systems impacts. The SDGs reference food security and agriculture (2), water and sanitation (6), ocean and marine resources (14), and terrestrial ecosystems (15) as areas for sustainable management and development. Applying this broad lens is useful in assessing how an STE that is, for example, focused on energy transition is, or is not, addressing social and ecological systems impact.

3. Developing and applying the framework

Thus far, we have developed a three-part evaluation framework based on an extensive literature review. Our next challenge was how to operationalize this framework and develop indicators and methods that can be practically applied. Early versions of the framework were applied, tested, and refined at the operational level through a series of seven research projects from 2014-2018. Working with practitioners has provided valuable insights that complement the theoretically derived framework. We are then able to provide a detailed operationalized framework with indicators and methods based on both theory and practical experience. Cases included:

- The *Local Economic Development Lab* (LEDlab) was an STE focused on developing employment and income generating opportunities for residents of Vancouver, Canada's Downtown Eastside. An early version of the framework was used to assess the LEDlab with a particular focus on policy impact.
- The *TAF Low Carbon Neighbourhoods* project assessed the direct and indirect effects of low-carbon neighbourhood projects in Toronto, Canada on greenhouse gas emissions reductions, on health, equity and/or economic objectives, and on contribution to larger sustainability transition goals. We developed and applied a 'light-touch' (simplified self-assessment) version of our evaluation framework for this project.
- A short project investigated how the *Suncor Energy Foundation's* participation in social innovation investments has affected the organization itself – in other words, what was the social, institutional or financial return on investment of these investments focusing on institutional change within the organization.
- In collaboration with *Sustainable Canada Dialogues*, we adapted our framework to generate an evaluation approach for assessing projects that aim to further Canada's commitments to reduce greenhouse gas (GHG) emissions and transition to a low-carbon economy.
- *Mistra Urban Futures* (MUF), headquartered in Gothenburg, Sweden has a vision of sustainable urbanisation where cities are fair, green and accessible and a mission to "generate and use knowledge for transitions towards sustainable urban futures through reflective co-creation at local and global levels." (Mistra Urban Futures, 2015). We developed an evaluation framework to capture the societal effects of MUF.
- *The Institute for Advanced Sustainability Studies* (IASS) is a transdisciplinary research institute based in Potsdam, Germany with a focus on sustainability. An adapted version of this framework was used to assess the societal effects of IASS.
- *The Energy Futures Lab (EFL)* in Alberta, Canada is an STE with a goal of fostering transition to a sustainable energy system in the province. The Energy Futures Lab was the focus of Williams' dissertation and provided a more complex case developing, applying and testing the framework over a 4 year period. While the goal of this paper is to present a new framework for assessing STEs, a

forthcoming paper will provide a more in-depth exploration of application to the EFL case, describe research methodologies appropriate for assessing STEs, and present empirical findings.

Through the implementation and assessment of different versions of our evaluative framework in practical cases, a number of key insights emerged that have influenced the design of the framework proposed in this paper. First was a confirmation of the value of the multi-level perspective (MLP) of transition theory. Practitioners saw value in this transition framework in the design and implementation of their programs. In addition, the MLP becomes a helpful framework with which to map indicators of systems transition. A second insight is the potential role of personal transformation in systems change. The SEF case reinforced the transformations literature focus on the importance of individual change in values and worldviews to support systems transition (O'Brien et al., 2018; Hölscher et al., 2017). The role of personal change is therefore included in the sustainability transitions impact component of our framework. A third insight is the concept of 'markers' of transition. This concept provides a way to conceptualize how a given STE is contributing to sustainability transition even though the transition may still be underway or may take longer to occur than the STE or research project lasts. Fourth, several cases foregrounded the co-production approach to STEs and prompted a deeper investigation of this literature and inclusion of co-production process and effects indicators in our framework.

Finally, the biggest insight was in the development of the three-level framework of process, effects, and sustainability transition impacts. Our initial framework did not include process elements at all and had a rudimentary conception of sustainability transition impacts. Through this series of cases, the importance of the relationship between STE process (and inputs and external context) and its effects became clear and, supported by literatures such as transition management and co-production, possible to include in an evaluation framework. In addition, the gap between capturing societal effects and how an STE is actually contributing to sustainability transition in our approach also became clear. This led to a deeper investigation of additional literatures to more concretely articulate the concept of sustainability transition impacts.

4. Evaluation framework

Integrating the elements discussed in the previous sections of this paper leads to our proposed three-part evaluation framework of process, societal effects, and sustainability transition impact as follows:

- Process – fairness and inclusivity of the process, the quality and appropriateness of the tools and methodologies used, and the adaptive and reflexive capacity of the process
- Societal effects –short term "splash" outputs and medium term "ripples" or outcomes of the process
- Sustainability transition impacts – longer term impacts that reflect societal transition such as socio-technical systems and governance, interlinking regime rules and behaviours, reinforcement at multiple levels, actors and practice, and socio-ecological systems

As shown in Tables 1 and 2 above, the categories in the first two levels of this framework are derived from the literature. Since the third level of sustainability transitions impacts has required the development of a new set of evaluation categories, it is presented in more detail in Table 4. For each category, we operationalized the framework with reported (regular font) and observed (*italic font*) indicators. Reported indicators are ones that may be reported by STE participants, design team members, or other stakeholders that are interviewed or surveyed. Observed indicators are those assessed by researchers through, for example, design document reviews, meeting observations, or review of publicly available documents such as government policy briefs or annual reports.[4]

The framework developed here addresses each of the evaluation challenges raised in our introduction. The use of a development pathway approach allows inclusion of external context shifts and STE impacts in multiple domains. The interplay between system elements can be captured through transition impacts categories such as interlinking regime rules and reinforcement at multiple levels. Markers of transition can be used in the short-term to assess potential or likely contribution to sustainability transition when direct attribution in a complex system is difficult if not impossible. Enabling STEs to assess their own processes, effects, and impacts provides an opportunity for learning and experimentation *within* the STE which provides value to STE designers and practitioners. Finally, the links between process, effects, and impacts are helpful for STEs in articulating the value of investing in good process design, facilitation, and delivery.

5. Conclusion

In this paper we have focussed most attention on evaluating sustainability transition impacts since these have been less discussed in the literature. We plan further research on understandings of development pathways themselves. For example, worthy of further exploration is the heterogenous nature of development pathways. In the midst of our current unsustainable pathway, we also see sustainable trends such as the dramatic acceleration of electric vehicle adoption, rapid drops in prices of renewable technologies, and institutional investors divesting from fossil fuels. Do these represent a changing development pathway? Is it possible to have a pathway pointing in multiple directions at the same time? These questions deserve more attention in future research.

A final element we are exploring is the concept of 'markers of transition'. System transitions (especially energy system transitions) occur over periods of years or even decades (Schot and Kanger, 2018). Given that an STE (and an accompanying research project) may last for only a small portion of that time, this presents difficulties in assessing long term sustainability transition impacts. Using the three-part framework we have developed, we can anticipate (based on process characteristics and societal effects) certain types of impacts if certain 'markers' of transition are present. For example, do reported effects point to transitions? Do they incorporate features that might be expected to support transition? We plan to further develop the 'markers' concept in an ongoing research collaboration between The Atmospheric Fund and the University of Toronto.

This paper outlines an approach to evaluating the process, impacts and effects of STEs as a contribution to ongoing discussion within the transdisciplinary sustainability community as sustainability transition experiments continue to generate interest from both researchers and practitioners. We believe the framework proposed here holds great promise in supporting evaluation efforts of researchers and practitioners. The framework improves on the literature in several ways: (i) it is comprehensive, covering multiple relevant dimensions of evaluation; (ii) it is strongly rooted in the theoretical literature, and provides a clear theoretical rationale for the evaluation categories we propose; (iii) it was developed and tested in multiple case studies; and (iv) it provides, for the first time, a systematic attempt to conceptualize longer term sustainability impacts, and integrate that into an evaluation framework. For practitioners, the framework includes a range of transition impacts and potential markers of transition. A more nuanced understanding of what contributions to sustainability transition look like in practice will help STE designers, facilitators, and participants in making decisions about project scope, process, and implementation. These characteristics

[4] Supplement 3 maps keywords and concepts from our literature review along with the Sustainable Development Goals to our proposed evaluation framework.

Table 4
Sustainability Transition Impacts and Development Pathways (See Supplement 3 for further detail and sources) Formatting: regular-effects directly reported; *italic-effects observed by researcher*. Operationalization framework approach adapted from (Schäpke et al., 2017).

Development Path Characteristics	Category	Sustainability Transition Impact Indicators
Socio-technical systems and governance	Governance role and relationships	Participants report inclusion of new actors and issues in public spaces and discourse Participants report changes in decision making (or who gets to participate in decision making) that affects the STE *Changes in practices of participation and new forms of participation in governance processes observed through published terms of reference*
	Reduced barriers to transition	Participants report influence on reducing barriers to transition such as institutional inertia, built infrastructure, or policy *Reduction in incumbent actors' actions to resist, delay or derail low-carbon transitions* *Leadership, resources, information, values and beliefs present to support transition* *Changes in development path dependencies and/or adoption of adaptive management practices*
Interlinking Regime rules and behaviours	Justice	Participants report equitable distribution of costs and benefits of transition Participants report STE has contributed to reduced marginalization of peoples *Assessment of distribution of benefits of STE initiative portfolio*
	Changes in regime practices	Participants report new or changed sustainable routines (i.e. "rules of the game") within regime organizations Participants report new ways of sustainability thinking, frameworks or narratives that have become embedded in institutions or policies *New sustainable practices/norms evidenced in policy statements or reports*
Reinforced at multiple levels	Niche-Landscape Alignment	Participants report project alignment to broader social, political and cultural trends *Niche innovations developed in STE aligned with broader social, political and cultural trends supporting sustainability*
	Multi-level	Participants report changes at multiple levels (e.g. organization, region, national, global) *Observed cross-scale changes and reinforcing links (e.g. national policy supporting regional niche innovation)*
Actors & Practices	Actor roles and relationships	Participants report a greater sense of agency/efficacy; greater agency in influencing changes to practice, i.e. "rules of the game" in organizations Participants demonstrate reflexivity on the role they are playing in systems transition; development and adoption of collective purpose and vision; improved problem solving capabilities between actors/participants Participants shifting roles Participants report actions at multiple system levels *Greater social cohesion across groups related to STE* *Are the boundaries and relations between sectors shifting in the STE domain (between public and private, for-profit and non-profit, formal and informal)?* *Which (new) actor roles are (re-)emerging in the STE context?*
	Changes in collective practices	Participants report development and adoption of new sustainable narratives, practices, values, worldviews or norms Participants report sustainability norm change and/or adoption within publics *Shifts in public narrative related to focus of STE (e.g. energy transition)*
Social and Ecological systems		Participants report improvements to the ecological capital in geographical area of STE focus Participants report ways in which STE take into account both human and ecological well-being, and STE acknowledges and protects ecosystem services (for example, include food security) Participants report ways in which the STE has contributed to meeting SDG goals *Effects of STE aligned with supporting SDG goals*

also support the potential to apply the framework beyond STEs and at multiple project scales. Finally, we hope that, by paying attention to markers of transition impact, practitioners (working in concert with transdisciplinary researchers) may adjust their course and navigate through an ever-changing systems landscape.

Declaration of Competing Interest

The authors declare that there are no conflicts of interest.

Acknowledgements

The authors wish to thank University of Toronto graduate students Kimberly Slater, Pani Pajouhesh, and Grégoire Benzakin for their contributions to the development of the three-part evaluation framework referenced in this paper. We also thank our anonymous reviewers for their valuable critiques and suggestions. Williams gratefully acknowledges the financial support for this research provided by Mitacs Canada, the Social Sciences and Humanities Research Council of Canada, and The Natural Step Canada.

Appendix A. Supplementary material

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.envsci.2019.10.012.

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