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Exploring the role of failure in socio-technical transitions research

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ABSTRACT

In this paper, we offer a comprehensive and interdisciplinary review of 'failure' in transitions research. What is meant by failure, and is the community biased against it? How is failure explained through different perspectives? How can failures be addressed more appropriately in transitions studies? We synthesize a large body of evidence spanning transitions studies, innovation studies, science and technology studies, organisation and management studies, policy studies and the history of technology to probe and sharpen these questions. We examine within these literatures the instances and possibilities of success with transitions and discuss why this may be problematic, organising our analysis around four types of bias (selection, cognitive, interpretive, and prescription). In addition, we review three 'families' of framings of failure put forward in and around the socio-technical transitions literature, notably discrete failure events, systemic failings and processual accounts of failure, and discuss how they can be constructively put to work.

1. Introduction

Transitions studies seek to understand how fundamental transformations of socio-technical systems unfold and how these may be governed (Markard et al., 2012). The challenges of bringing about purposeful socio-technical transitions are significant, due to strong path-dependencies and lock-ins, and uphill struggles with the introduction of radical innovations. In the case of *sustainability* transitions, an additional difficulty concerns altering the directionality and performance criteria for innovations (Kemp and Van Lente, 2011), independently of agreeing on what these may be.

So, it is perhaps unsurprising that historical examples or case studies of realised transitions – though by definition rare, contested and challenge-ridden occurrences – have taken a central place in the early development of this field as exemplars underpinning conceptual elaboration, analytical constructs and pattern recognition exercises. Indeed, so poor are the odds, and so rare are the opportunities, for introducing far-ranging system change that significant attention has been put on demonstrating that such change *is possible* ('it has happened in the past') and that much *can be learned from* historical exemplars. Transition challenges are exacerbated for deliberate transitions efforts (i.e. motivated by specific end-goals, normative orientations, or institutional transformation), as opposed to transitions driven primarily by market and technological dynamics without necessarily challenging existing institutions (Fouquet and Pearson, 2012; Turnheim and Geels, 2012). As a result, the field may have put too much emphasis on the positive aspects of

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socio-technical change and 'successful' transitions (in the sense of materialised by substantial change or reconfiguration). The field, in simpler terms, by overemphasizing 'winners', may have neglected to examine with significant vigour and vim the 'losers' or 'failures' (Bauer, 2014; Braun, 1992). Recent research has started to engage more systematically with the 'flipsides' of socio-technical transitions, including comparisons of patterns of regime destabilisation and resistance in past transitions (Martínez Arranz, 2017), institutional decline processes in the wake of crises (Newig et al., 2019), or 'unsustainable' transitions (Markard et al., 2020), but this line of inquiry is still only emergent.

In this paper, we offer a comprehensive and interdisciplinary review of 'failure' in transitions studies. We ask: (1) What is meant by failure, and is the community biased against it? (2) How is failure explained through different perspectives? (3) How can failures be addressed more appropriately in transitions studies? We synthesize a large body of evidence across various literatures to probe and sharpen these questions. We find significant evidence of potential building blocks for more systematic investigations of failure as an important understudied topic, within transitions studies and innovation studies but also more widely.

The study proceeds as follows. In section 2, we present our methods. In section 3, we examine the various dimensions of the field's emphasis on the instances and possibilities of success with transitions and discuss why this may be problematic, organizing our analysis around four types of bias (selection, cognitive, interpretive, and prescription). In section 4, we review nine relevant perspectives on failure, which we analytically group within three 'families' of framings of failure put forward in and around the socio-technical transitions literature, notably discrete failure events, systemic failings and processual accounts of failure. There we also discuss how this evidence of a productive – yet rarely systematic – engagement with failure in the context of transitions research (involving different perspectives, levels, processes and findings) can be constructively put to work. Section 5 reflects on the biases and perspectives identified, while section 6 concludes with constructive suggestions for addressing failure in transitions studies.

2. Research design: an interdisciplinary and integrative review

Our primary method for this study was a comprehensive, integrative and interdisciplinary review. Such integrative reviews are deemed most appropriate when the research aim is to compile and integrate a large body of evidence, typically with the aim of identifying the current state of knowledge and specific research gaps (Whittemore and Knafl, 2005). An integrative review is most useful for exploratory questions that seek to synthesize insights from a variety of perspectives and disciplines, or areas where insufficient data exists to conduct a systematic review or meta-analysis (Cooper, 1998; Fink, 1998; Shaw, 2010).

Due to the exploratory nature of our exercise, we have sought to take a broad scope when considering relevant literatures dealing with various aspects related to failure in and around transitions studies. Accordingly, we have considered contributions from innovation studies (innovation processes, innovation policy, innovation management and economics), organisational change (firm-level and population level considerations), Science and Technology Studies (notably constructivist perspectives), technological systems perspectives, evolutionary perspectives, and so on, along with more conventional perspectives from economics and policy literatures (market failures, policy failures) when these have percolated through to scholarship on innovation and transitions. Although different in its focus and content, the methodological approach mirrors that of van Mierlo and Beers (2018), who also began by selecting research traditions, searching for core papers, and then snowballed using the bibliographies of those papers – in their case focussing on the problem of 'learning' in sustainability transitions.

To widen our sample of academic research, we thus searched Google Scholar, the most comprehensive repository of scholarship because it includes multiple databases including Scopus, Web of Science, and books, for studies published on the topic of failure in transitions in the past 40 years (from 1980 to 2019). We searched for associations of terms containing the root "fail~" along with other terms including "transitions", "project", "innovation", "technology", "industry", "socio-technical", "evaluation", "management", "learning", "organisation" in the titles, abstracts, and keywords of English based articles and books. We then repeated the search substituting "disappoint~" for "fail~". After ruling out irrelevant entries based on titles and abstracts, and further snowballing based on bibliographies, we identified a corpus of studies that we then analysed and parsed according to our own expertise.

In doing so, our main inclusion criterion concerned relevance to the problem at hand and disciplinary positioning: we excluded a) a large number of entries that only referred to 'failure' in a colloquial way or in relation to evaluative statements about methods and research achievements (i.e. in ways not related to innovation, innovative projects, socio-technical change or purposive transitions), b) entries from beyond the social sciences or sharing no direct proximity with innovation and transitions studies (e.g. while 'market failure' is an important theme in economics, we have decided to review only contributions mobilising these in relation to radical innovation and transitions (see section 4.2.1)), and c) entries that we judged as addressing the topic overly narrowly (e.g. without drawing broad generalisable implications for particular theories, research fields, policy or practice). The resulting 190 studies are cited in this paper.

To further structure this review, we have chosen to organise what we identify as 'perspectives' according to what we interpret to be the core framing put forward. We observe a striking variety of framings and arguments, as well as different kinds of objects considered as failing, exposed to failure, or transformed through experiences of failure. In order to intelligibly convey this variety, for each broad perspective, we considered aspects of the literature including technological focus (or sociotechnical system), temporal scope, attribution of success or failure, core processes and kinds of explanation (if any).

3. The perils of success? Four criticisms and biases in transitions studies

Our first question centres on how the transitions community defines, focuses and engages with failure. We deploy the term 'bias' to refer to an inclination or preference pattern rather than a more pejorative or active prejudice.

3.1. Selection biases

The transitions literature has largely focussed on understanding how transitions come about. Mobilising historical cases of *realised* transitions has been a major methodological entry point for the study of past transitions, namely due to the importance of exploring the relevance of a phenomenon that escaped prior analytical frames (notably due to its long-term, multi-dimensional and uncertainty-bound nature) (Rip and Kemp, 1998). However, focussing on cases where substantial transformative change has occurred (i.e. 'realised transitions') is a highly oriented strategy that – though maximising informational content through the mobilisation of exemplars (Flyvbjerg, 2006) – may lead to highlighting certain processual features over others.

The Multi-Level Perspective (MLP) (Geels, 2012; Rip and Kemp, 1998), for instance, "has been used as a productive framework to describe and analyse quite a substantive number of historic transition cases, and to sketch possible transitions emerging" (Jørgensen, 2012:996). The deliberate study of failed historical cases, e.g. as possible analogues for current developments (Johnson et al., 2016), is only emerging. The Technological Innovation System framework (TIS) engages with problems and obstacles along innovation paths, interpreting these as system weaknesses or failures (Bergek et al., 2008; Jacobsson and Bergek, 2011). These are primarily mobilised to argue for the strengthening of TIS functions, i.e. as rationale for corrective intervention (see section 4.2.1), though there is a growing number of studies examining disappointments for their own sake (see section 4.3.3). Similarly, while studies mobilising Strategic Niche Management (SNM) are receptive to sources of success and failure with socio-technical experimentation (van der Laak et al., 2007), failure cases tend to be mobilised with meliorative motives to pinpoint essential processes that can support more effective interventions.

While certain studies dealing with potential 'transitions-in-the-making' pay attention to the problems inhibiting or slowing down progress along emerging trajectories (e.g. struggles, systemic shortcomings, misalignments) (Berggren et al., 2015; Mazur et al., 2015; Wells and Nieuwenhuis, 2012), they only partly circumvent this bias: cases tend to be selected where substantial progress is expected and problems along the way are treated as disappointments or setbacks. Rarely are we presented with situations for which such problems become the end of the road, with stories of total shambles or inevitable failures – though no doubt there is rich empirical material waiting to be mobilised. The field has also to date privileged paradigmatic or critical cases (Flyvbjerg, 2006) of realised (or potentially realisable) transitions over alternative research strategies, such as purposely selecting 'deviant' cases of failed transitions or of unsustainable transitions.

According to Shove and Walker (2007), such a selective strategy may lead to eluding 'missing transitions' that do not fit the bill, because a) they are not heading in the 'right' sustainable direction, or b) they are not leading to the development of new systems (but rather to "the loss or abandonment of previously important sociotechnical systems"). Others have suggested that there has been too much emphasis on 'winning' innovations (Genus and Coles, 2008). Further, privileging realised transitions cases risks introducing a significant selection bias leading to a) over-emphasising deterministic logics over path pluralism or counterfactual analysis of paths not taken (Stirling, 2011) or b) mis-representing the more likely outcome of failed or difficult transitions.

3.2. Cognitive biases

Failure may be much less straightforward to capture and single out than success, owing to its multifarious and multidimensional (Sovacool, 2014), relatively invisible and uneventful (Wells and Nieuwenhuis, 2012), evasive and pervasive nature.

Whether researchers actively avoid stories of failure, or unconsciously omit them, commitments to positive interpretive frames (e.g. success, entrepreneurship, transformative change) and desirable outcomes can blind the research community to more negative ones. This is particularly true for those who have normative commitments to the positive enactment of change paths – which may be the case for transitions scholars pertaining to a tradition of engaged scholarship (van de Ven, 2007) and/or action research (Wittmayer and Schäpke, 2014). Furthermore, transitions studies may be overwhelmingly interested in disruptive change (at the expense of more incremental, tentative or fumbling forms of change) and radical novelty (at the expense of decline, less dramatic innovation, or technologies in use).

Failure may also be inherently more difficult to circumscribe than success. Indeed, while success may be characterised in more definitive terms (e.g. marked by the crossing of certain thresholds such as market penetration rates), a failure episode is inherently less definitive and more relative, notably insofar as it can be interpreted as an 'early attempt' (Johnson et al., 2016) not yet successful and may also be the object of a subsequent resurrection (Goldenberg et al., 2004). So, innovation and transition failures may be more ambiguous to evaluate than successes (Brix, 2015; Feola and Nunes, 2014). Furthermore, it may also be more practicable to learn from failure than success, because causes may be relatively easier to identify, isolate and strategically mobilise (Brix, 2015; Cannon and Edmondson, 2005; Maidique and Zirger, 1985).

Regardless of the exact proportion of failed innovations or transitions over successful ones, it is likely that archival datasets disproportionately represent success cases, simply by the continuity of records that survival implies. This may be particularly the case for 'early failings' with experimental projects; initiatives or the failure of early business ventures that have not have established records of management practices, but also evidenced with more perennial organisations for which the cost-benefit of maintaining archival records comes into play (Kirsch, 2009).

3.3. Interpretive biases

There is a temptation running through transitions studies, which is the object of recurring (sometimes misplaced) criticism, to retrospectively simplify transitions dynamics around streamlined narratives of transformative change. Two main points of constructive criticism regarding interpretive biases stand out.

First, there is a recurring criticism of 'niche-driven bias' (Berkhout et al., 2004) in transitions frameworks, notably concerning risks a) of overemphasising the potential of projects and socio-technical niches to bring about change in Strategic Niche Management (SNM) (Hoogma et al., 2002; Kemp et al., 1998; Seyfang et al., 2014), or b) of primarily focussing on the 'heroic' struggle of niche actors against established regimes and associated storylines in the MLP (Geels, 2004, 2002a). Indeed, a distorted focus on niche momentum and heroic narratives risks conveying an illusion of linear progression (for niche formation, path creation, or system change) and misrepresenting the significant difficulties encountered by change advocates (Seyfang and Longhurst, 2016). Furthermore, it may also "obscure the productive role of processes of failure and decline in achieving sustainability" (Newig et al., 2019:18).

Second, analytical narratives presented within transitions studies may focus on the most eventful and salient developments at the expense of greater subtlety about difficulties encountered, simplifying "a complex diversity of socio-technical configurations […] into unrealistically homogenous niches working against an equally problematic homogenous regime" (Smith, 2012:199; see also Genus and Coles, 2008; Sheller, 2011), or neglecting less vocal or visible actors, interests and normative framings (Stirling, 2015, 2009).

Consequently, there is a clear risk that by privileging narratives of success, the transitions literature may elude or misrepresent the importance of failed innovation, failed transitions ('transitions that never happened'), negative consequences and side-effects, and more generally difficulties encountered with transitions processes in the face of considerable uncertainties. While struggles, difficulties and disappointments with emerging trajectories are the object of increasing attention in transitions scholarship, they tend to be interpreted as delays or setbacks (i.e. successes in the waiting) rather than dead-ends or failures. More generally, it has been observed that scholarship related to innovation has a tendency for focussing on upward swings and on winners, with comparatively little consideration of aspects related to failure (Sovacool, 2014).

In this context, we ask whether a principle of symmetry should be taken on-board that could enable narratives that more centrally consider stunted developments, setbacks, impasses and other deviations from stylised accounts, and what may be learned from such a research orientation applied to transitions and more purposive efforts seeking to support them.

3.4. Prescription biases

Transitions research is often motivated by societal challenges and the search for solutions, by engaging directly with audiences from policy and practice. This is particularly the case with research on 'sustainability transitions' (as opposed to *socio-technical* transitions more broadly), and particularly with Transition Management approaches (Loorbach, 2010), which are involved in transdisciplinary research and the co-creation of knowledge through action research methods and experimental interventions (Frantzeskaki et al., 2018; Nevens et al., 2013; van den Bosch and Rotmans, 2008). Besides the co-creation and initiation of sustainability initiatives (often at local level), transitions research is also influencing public policy at national (Kemp and Martens, 2007; Kern, 2011) and international levels (Köhler et al., 2019).

An ongoing point of debate within science-policy discussions about socio-technical transitions concerns the mobilisation of evidence in policy contexts. Two opposing views co-exist: a) a realist perspective calling for more systematic evidence and evaluation in view of 'better-informed' decision-making, and b) a constructivist perspective, recalcitrant to the over-formalisation of empirical evidence in light of the perils of its instrumental translation in narrow policy frames and arbitrary political decisions. At its extreme, the realist perspective veers towards positivism and mechanistic advice concerning interventions, while the constructivist perspective prefers to uphold a message about inherent messiness and situated nature of processes involved. In-between those extremes, there is significant scope for critical-realism, co-shaping of science and policy, and so on. But how do these different postures affect a prescription bias in sustainability transitions research?

Firstly, transitions scholars may wish to prove that alternative courses of action *are possible*, or unreflexively engage with initiatives for changing the course of action. This can lead to an unbalanced emphasis on hopeful prescriptions. Selection biases (see section 3.1) may be further exacerbated as research outcomes come into contact with decision-making and prescriptions. A recurring strategy of grey and policy literature is to focus on aspirational exemplary cases, but an asymmetrical focus on and explanations of success carry a risk for reproducing illusions of momentum and bolstering expectations regardless of the feasibility of developmental paths, and ultimately induce slippage into familiar evaluation frames that run counter to the need for cultivating diverse transformational knowledge and action modes. In other fields, notably public policy, governance, and public administration, the concept of "panacea bias" has even emerged to describe this tendency to become bonded to particular prescriptive measures—where scholars come to deceive themselves into thinking a single, monolithic policy solution (such as a carbon tax) will work despite any contravening evidence (Gilligan and Vandenbergh, 2014; Ostrom, 2007).

Secondly, raised policy salience (of transitions research findings) comes with greater emphasis on evaluation, metrics, and more systematic comparisons:

"As transitions researchers seek to engage in evidence-based policy environments and argue the transferability of action research projects to other contexts, the development of adequate and relevant indicators and measurement techniques will be important" (Köhler et al., 2019)

Such endeavours provide scope for re-thinking the nature of the processes under scrutiny and the various biases introduced, including an overemphasis on realised transitions and a relative neglect of failures.

Two criticisms further ground the importance of more balanced selection of cases examined and lessons derived from them: a) there is a risk with transitions and transitions policy of seeking to move "too fast, too big, too early" with particular innovations, instead of developing interventions that are persistent and continuous, generate aligned signals, and are balanced across multiple options to avoid the entrapments of single large-scale options and their risks of failure (Grubler, 2012); and b) achieving fundamental green transformations may require novel forms of 'courageous risk-taking' from the state and a need to engage more acceptingly with failure (Mazzucato and Perez, 2015).

We return in the paper to addressing how to respond to these collective biases in Section 5.

4. Perspectives on failure in socio-technical transitions research

Our second and third questions centred on how failure is conceived and described in the literature. The main challenge here consists in making sense of a large and heterogeneous body of literature, synthetically conveying the contributions within it, and interrogating their relevance to the problem at hand. In practical terms, this involves iterations of analytical sorting and clustering.

In a first step, we have grouped the identified contributions within nine distinct perspectives on failure encountered in and around transitions studies, presented in Table 1, according to what we interpret to be core framings put forward and analytical themes. Each perspective can be linked to a particular combination of research traditions, frames 'failure' in a particular way, and takes a particular analytical unit as starting point. While these perspectives can be held together by a significant degree of coherence concerning analytical objects and framings, there is also a degree of heterogeneity and sometimes sub-strands within them. Conversely, there are also some overlaps between perspectives, which may be signs of a) ambiguities stemming from our interpretive categorisation or b) common lineage or cross-fertilisation between perspectives. For instance, perspectives falling within 'failure along socio-technical trajectories' are indebted to constructivist and historical approaches ('autopsies of innovation failures') and 'evolutionary failures' approaches. In other cases, as with 'evaluation of failures' and 'learning approaches', our proposed distinction is not so much based on the bodies of literature themselves (which overlap significantly) but on the kinds of arguments put forward and the performative context of meanings ascribed to failure (i.e. a focus on diagnosis and attribution, and a focus on reflexive adaptation, respectively).

In a second step, we also sought to cluster these perspectives into broader 'families of perspectives', according to a combination of thematic and analytical criteria, including the focal analytical unit, considerations about system boundaries and analytical levels, the rationale for focussing on failures, the dominant analytical style. This iterative and recursive process enabled us to identify three distinct 'families of perspectives':

- **Discrete failure accounts**. Perspectives within this family are primarily focussed on single or discrete failure events and episodes. Explanatory styles vary but are concerned with diagnosing failure, and deconstructing its sources, antecedents, effects or processes. Failure is framed in contradistinction to 'normal functioning', 'expected performance', or 'orderly path'.
- **Systemic failings accounts**. Perspectives within this family are primarily focussed on dysfunctions and failings as systemic phenomenon. Explanatory styles tend to be managerial and prescriptive, concerned with identifying deficits and harnessing opportunities for corrective interventions of various kinds. Failure is framed as calling for a shift of analytical focus to capture neglected systemic dimensions and to enable greater consideration linkages between various dimensions.
- **Processual accounts of failure**. Perspectives within this family are primarily focussed on failure as processual phenomenon in the context of broader dynamics. Explanatory styles are processual, emphasise uncertainties, indeterminacies and embeddedness, and suggest a need for broadening out and contextualising. Failure is framed within longitudinal development trajectories and journeys.

This higher-order clustering is the product of an interpretive process and can hence be discussed or contested. Our main criterion, which enabled us to stabilise and close down our choice following multiple iterations, is the relevance of the resulting clustering in addressing our third research questions. In essence, this has led us to prioritise differences in terms of analytical posture: *diagnostic and deconstructive*, *managerial and prescriptive*, *contextual and processual*.[1]

In section 5, we turn back to our clustering, namely concerning inevitable ambiguities, overlaps and interactions between approaches, and other transversal dimensions arising.

4.1. Diagnosing and deconstructing discrete failure episodes

These contributions focus on discrete failure events and episodes, and are particularly concerned with diagnosing failure, and deconstructing its sources, antecedents, effects or processes, as well as what these reveal about systems under scrutiny.

4.1.1. Technical system failures as anomalies

This perspective primarily focuses on technical system failures, accidents or breakdowns arising in industrial facilities and large technological systems.

Technical systems are supposed to work according to expectations, technical specifications and operational performance criteria. Whether these concern individual sites, like power plants and industrial facilities, or larger units of analysis, like infrastructures or large technical systems, technical failure is largely considered as irregular, abnormal or undesirable occurrence that needs to be avoided or corrected.

From engineering and operational management perspectives, failures are seen as punctual, irregular or unexpected events with low probability but potentially high impact. Technical system failures and accidents are perceived as anomalies (odd, rare occurrences)

[1] We have decided to group 'autopsies of innovation failures' within the 'discrete failures accounts' because of its primary unit of analysis, although it equally fits in 'processual accounts of failure' due to the inherent attention to process and context in constructionist and STS perspectives on failure. Similarly, we have decided to group 'learning approaches to failure' within the 'systemic accounts of failure' because of its primary unit of analysis and core framing of failure, although the explanatory mode within this approach is largely processual in nature.

Table 1
Overview of perspectives, core framings and analytical focus (Source: Authors).

	Perspective	Focal analytical unit	Core framing of failure	Explanatory focus	Related literature
Discrete failure accounts	Technical system failures	(large) technical systems, infrastructures, crises	as system anomalies, accidents, breakdowns, crises	failures as entry point to 'systemness', dependencies & vulnerabilities	engineering, history of technology, large technical systems
	Evaluations of project failures	projects, innovation interventions	as negative or disappointing performance	measure failure (against objectives), understand its antecedents and sources	evaluation studies, organisational change, management
	Autopsies of innovation failures	innovation process and practices, actor-networks, relevant social groups	as mundane, idiosyncratic, constructed, part of innovation processes	unpack the social construction of innovation; meanings & performativity; innovation as journey	science & technology studies, sociology, history of technology
Systemic failings accounts	Generalised systemic failures	markets, innovation system, socio-technical systems and trajectories	as system weaknesses (deficits, unpropitious conditions) requiring corrective intervention	identify neglected system conditions leading to suboptimal outcomes; reframe loci of intervention	economics, policy, governance (of innovation, of system transformation)
	Policy failures	policy process, policy actors, policy regimes, advocacy coalitions, policy mixes	as inability to implement effective policy interventions or programmes	sources of inadequate, ineffective or undesirable policy arrangements	policy, governance, comparative political history, political economy
	Learning approaches to failure	projects, innovation activities in organisations	as opportunities for reflexive learning or addressing learning deficits	modes of experimentation, learning & discovery; strategic reframing (adaptive management, re-orientation)	organisational change, management
Processual accounts of failure	Evolutionary failures	organisations in industries, industries in environments	as vital (inevitable or necessary) part of evolutionary processes (variation, selection, retention, adaptation), but often treated as residual	alignments and misalignments; generative patterns (new search paths, re-orientations); degenerative patterns (negative feedbacks, downward spirals)	organisational change and management, industry dynamics, evolutionary economics
	Transition failures	socio-technical systems & trajectories, industries	as linked to dynamics of stagnation, destabilisation and reconfiguration (later stage of system lifecycles); as persistence & continuity ('transitions that never happened')	trajectories and patterns; sources of stability & instability; enacted strategies	large technical systems, socio-technical transitions studies, industry dynamics, social movements
	Radical innovation failures	innovations, innovation trajectories	as inherent to radical innovation processes; as triggers and events along socio-technical trajectories	innovations, niche development, path creation; alignment & embeddedness in wider structures; the importance of process	innovation studies, socio-technical transitions studies

Source: Authors

requiring corrective measures. The literature on technological risks and its management is concerned with handling such exceptional events (e.g. anticipating, avoiding, mitigating, minimising). Technical design and development is concerned with minimising or avoiding the eventuality of failures: designing fail-safe systems as "systems that have tolerances, redundancies, and fail-safe elements that accommodate the many vagaries of normal technological operation" (Downer, 2011:732)

Nonetheless, accidents do happen (Lagadec, 1990), their severity ranging from sub-optimal performance and punctual breakdown all the way to major accidents and catastrophic failures. The dramatic cases of nuclear power plant accidents at Fukushima, Three Mile Island or Chernobyl (Carlisle, 1997; Sovacool, 2011), hydroelectric dam collapses, energy blackouts, uncontrollable environmental pollution as with the Amoco Cadiz oil spill, Deepwater Horizon explosion and spill (Ansell and Boin, 2017), or major industrial accidents leading to human casualties and health hazards are important reminders of how bad technical failures can turn out to be. Large technical systems, characterised by significant complexity, tight coupling and interdependencies, are particularly exposed to the risks of problems and failures spiralling out of control (Hermwille, 2016; Joerges, 1988; Perrow, 1984; Sovacool and Cooper, 2013). However, while catastrophic system failure can in theory trigger the search for new paths, there is also often failure to seize such opportunities, notably in light of overriding injunctions of system reliability in large technical systems (e.g. tolerances and fail-safe elements, too big to fail, concentration of power, path dependence), creating dissonant situations whereby 'opting out' of existing commitments and computing alternative paths becomes framed as potentially disastrous (Joerges, 1988).

Implications for transitions studies. This perspective sheds light on the possibility of large-scale system failures, and how they are handled within engineering and managerial rationalities. It suggests that while technical system failures may be important triggering events that can reveal inherent inconsistencies, vulnerabilities, patterns of dependence and support transformative change efforts, systemic shockwaves are also often absorbed by systems in place, due to their sheer size and relevance or crisis management resources. It is important for transitions studies to better understand the different types of technical system failures, their explanation or interpretation (e.g. shocks or stresses) (Stirling, 2014), and the processes and conditions determining the kinds of responses observed, i.e. *when* technical system failures lead to transformations.

4.1.2. Evaluations of project failures as negative performance

This section focusses on conventional evaluation approaches, applied to failures within projects or innovation interventions. The evaluation of failures involves more or less systematic attempts at identifying and circumventing failure from success in order to understand core causal mechanisms. It is also important to question the goal that evaluations of failure may serve, namely by critically examining the context of their (mis)uses (De Rijcke et al., 2016; Ràfols, 2019). Indeed, performance evaluations are inherently problematic insofar as they 1) instrumentally simplify complex processes in ways that may produce ignorance, goal displacement or narrowing, and 2) they tend to be used as instruments of authority and control rather than as tools of discovery or learning (Ràfols, 2019, see also section 4.1.2).

Leaving aside the inherently idiosyncratic and constructed nature of 'failure' and the difficulties of causal attribution, evaluation seeks to measure performance and results against the stated aims of activities, projects, programmes, or organisations. It consists in "careful retrospective assessment of [interventions], their organization, content, implementation and outputs or outcomes, which is intended to play a role in future practical situations" (Vedung, 2010), and hence links performance to controls and learning. Evaluation approaches differ in terms of 1) the unit of analysis (e.g. projects, innovations, organisations, systems, socio-technical trajectories), 2) the processual scope (e.g. discrete 'tests' and performance thresholds, developmental or strategic focus), 3) gradations of failure (e.g. disappointing, interrupted or abandoned innovations and search paths), 4) explanatory dimensions considered (including internal/-external sources), and 5) methods (e.g. in-depth case studies, large-N studies).

Small-N and case studies of failures tend to start from single projects, interventions or organisations with the objective of mitigating internal and external sources of failure in project design or organisational sense-making (Brix, 2015; Chesbrough, 2010; Douthwaite et al., 2001; Shepherd and Kuratko, 2009). Building on Henderson and Clark (1990); Brix (2015), examining sources of failure with energy innovation, emphasises "the importance of identifying the assumptions and misbehaviours that are inappropriately utilized to design and organize for innovation", and proposes three generic origins of failed projects in organisations: failure to organize for innovation, failure to contextualise innovation, or architectural design failures (which combine both).

Large-N evaluations are usually oriented towards the identification of collective patterns, structural determinants and explanations for failure within comparable groups (Feola and Nunes, 2014; Freeman, 1973; Hopkins, 1981; Maidique and Zirger, 1985), revealing important neglected dimensions of success. Regardless, failure evaluations are usually instrumentalised in a search for corrective action and appropriate controls: failure tends to be interpreted as negative and damaging event that needs to be limited – such failure-avoidance framings are at odds with those focussed on reflexive learning and other developmental opportunities (see for instance sections 4.2.3 or 4.3.3).

Conventional project evaluation tend to measure project outcomes against the initial formulation of objectives, i.e. whether implementation has delivered the proposed goals and targets related to technical performance improvement, the development and/or commercialisation of products, or addressed externalities through policy interventions. A recurring problem with such intended or goal-rational strategies is that they offer little scope for making sense of or enabling deviations from original plans (Mintzberg et al., 1998) except for minor tweaks and reformulated objectives, leave little scope for processes of learning (from mistakes) and discovery (e.g. 'thinking outside the box'), partly sacrifice the need for long-term systemic outcomes, and incidentally affect future resource commitments through heightened perceptions of risk:

> "Failure is seen as a problem in a firm's economic activity [...] in the wake of a failure, organisations typically pursue strategies aimed at survival [and activities such as] containing costs, risky investments, organisational burdens" (Leoncini, 2016:376)

Indeed, when it comes to 'failed' or 'disappointing' projects, project evaluation rarely accounts for wider benefits accruing from learning potentials and capabilities that can be acquired through trial-and-error processes within project or between projects (Elmquist and Le Masson, 2009), namely because such wider impacts and knock-on effects rarely feature in the formulation of initial intentions, or are difficult to predict or actively manage (see section 4.2.3 for learning-oriented evaluation).

Implications for transitions studies. In the context of transitions, which are recognised as complex, multi-dimensional and long-term processes requiring systemic interventions, evaluations of success and failure are challenging. At a basic level, evaluation frames require clarity as to what is deemed to be potentially failing – so they are antidotes to the colloquial use of 'failure'.

Conventional forms of evaluation may however be counterproductive to the transformative purpose of transition interventions. The scope and nature of socio-technical transitions, and related interventions hence call for complementary forms of 'evaluation' that can capture the nature of transitions challenges and possible sources of 'failure', and enable second-order learning (see section 4.2.3). Such evaluation has been proposed as ways to capture the value of field-level learning (beyond independent units, projects, or interventions; recognising collective forms of action and learning), the processual nature of innovation (including the reformulation of goals), system dynamics and interdependencies, different temporalities (long-term goals, short-term interventions), and the importance of contextual changes (Patton, 2010; Technopolis, 2018).

Evaluating the broader outcomes of transition-oriented experimentation remains challenging. It requires an ability to contextualise individual projects (and their possible failure) in collective and distributed attempts at re-orienting socio-technical trajectories (see section 4.3.2) or supporting the creation of entirely new paths (see section 4.3.3).

4.1.3. Autopsies of innovation failures as deconstruction project

Within STS and constructive accounts of innovation processes, a recurring debate concerns the importance of upholding a principle of symmetry and resisting a bias for heroic and linear stories. Within the historiography of innovation and technology, 'failed innovation' has become an important theme. We provide an overview of both perspectives in the following.

(Constructivist) sociology of technology. Failed innovations and projects play a central role in STS (Latour, 1996; Law and

Callon, 1992; Pinch and Bijker, 1987). The social construction of technology (SCOT) perspective (Bijker et al., 1987) defines success with technological development as a process of 'closure'. The emergence of a 'dominant design' selects out the variety of problem definitions, meanings, interpretations, and alternative solutions brought forward by different social groups (Pinch and Bijker, 1987). This implies that for any successful innovation, there is a significant amount of "forgotten views and failed technological directions" (Rip and Kemp, 1998:358), and that failures may even reveal " processes that are more easily hidden in the case of successful projects and institutions" (Law and Callon, 1992:22).

One way to trace back failures becomes to investigate which directions or paths have become excluded, how and why. Law and Callon (1992), for instance, explain the failure of a technically successful aerospace project (the TRS.2 military aircraft project), by pointing to the contingent, iterative and erratic nature of project development trajectories – in this case the initial positive mobilisation of actors in external and internal networks was a fragile balance that was not maintained and eventually led to the 'killing' of a project that had failed to install itself as an 'obligatory passage point' between networks and maintain an active 'negotiation space'. Such accounts from the history and sociology of technology also point to the multiplicity and mutability of development paths, which are exposed to changing directions and fates, breakdowns and reversals.[2]

Latour (1996) suggests 'autopsies of failures' as means to explore the plural and transient interpretations of 'failed' innovation projects by exposing the interpretive and constructed nature of 'failure'. He urges for a symmetrical treatment of success and failure that does not retrospectively label that which has 'come into existence' as inevitable or predictable success against its counterpart. He suggests re-establishing a principle of symmetry (between success/failure, existence/non-existence), following projects "lovingly through their entire duration", and to focus on fleeting and fragile interpretations from various perspectives (relationism) (Latour, 1996).

A related stream of studies has been concerned with deconstructing the processes by which large engineering projects and visions have been halted, put on hold or abandoned in relation to struggles involving social groups 'outside' techno-economic spheres, e.g. influenced by mobilisation from civil society actors. Opposition to nuclear power installations (funded or even delivered) provide particularly salient examples (Felt, 2015; Fjaestad, 2015; Le Renard, 2018).

Given that socio-technical construction involves not a linear development but competing artefacts or socio-technical systems which can be approached through different phases (interpretative flexibility, stabilisation and closure), involve different social groups, meanings, technological frames and social processes, failures are both constitutive of socio-technical construction processes and their explanation (technical, organisational, social, political), plural (and hence contested) and contingent on developmental trajectories which cannot be *a priori* assumed. Failures hence emerge as an integral aspect of how technology is made, and a relevant line of enquiry.

History of technology. In the early 1990s, sociological accounts of failure and symmetry arguments revived related arguments within the history of science and technology (Bauer, 2014; Braun, 1992; Mumford Jones, 1959). The focus on failed innovation within the history of technology is motivated by a need to dispel illusions within conceptions of technological change as following an orderly path, determined by evolutionary superiority, economic rationality and linear progress (Braun, 1992; Kunkle, 1995). The innovation failures programme shed light on important aspects of failures, which can be taken up as propositions:

- failure is inherently multi-dimensional and situated (in time and place) (Braun, 1992);
- failure is idiosyncratic and calls for reflexive evaluation, given that "judgements of 'failure' are so perspectival in character that they are prone to a radical interpretive flexibility" (Gooday, 1998);
- failure is overdetermined and linked to multiple causes and problems;
- failure is a result of misalignments and/or inappropriate timing of mechanisms contributing to innovation, which can include "too radical nature of the innovation, a misjudgment of user needs or […] insufficient understanding of the 'production and use culture' of a technology" (Bauer, 2014); and
- failure is a "mundane and inevitable *prerequisite* of subsequent 'success'" (Gooday, 1998).

Implications for transitions studies. Autopsies of failure, seen as deconstructions and reconstructions of failure episodes, offer fruitful ground for continued research development, namely as they can support rich explanation of failures and their evaluation, the correction of inherent biases (see section 3), and the identification of key processes and mechanisms involved. Such approaches, focussed as they are on the meanings and politics surrounding innovation activities, are particularly relevant for addressing some of the core novelty biases within transitions studies in ways that are more reflexive and attentive to symmetrical treatment.

4.2. Harnessing and managing systemic failings

Contributions in this perspective are primarily focussed on dysfunctions and failings as systemic phenomena and are particularly concerned with identifying deficits and harnessing opportunities for corrective interventions of various kinds.

4.2.1. Generalised systemic failures as (corrective) policy intervention rationale

One explanation logic for failure taken up in socio-technical transitions research relates to analyses of the unpropitious conditions for (transformative, system) innovations. Such a perspective, largely indebted to the notion of 'market failure' in economics, primarily

[2] For this reason, this perspective fits also partly within 'processual accounts of failure', and indeed largely underpins related literatures.

offers rationales for (policy) intervention on the conditions for change, namely market, system, and transformative failures (Bleda and Del Río, 2013; Schot and Steinmueller, 2018a; Weber and Rohracher, 2012).

These are 'generalised failures arguments' - largely barriers, weaknesses or and deficits (market, governance, innovation, organisational failures) as rationales for corrective intervention. They may lead to an identification of new forms of steering, managing, governing that are more cognisant of current limitations, namely as they point to systemic requirements. So, such perspectives focus more on failings and deficits of appropriate conditions than on failures with innovation or transition *per se*, with a primary focus set at the level of innovation policy, and are underpinned by different problem definition (see Table 2).

While they carry important differences (e.g. a focus on static vs dynamic efficiency) (Jacobsson et al., 2017), at heart, they suggest that prevailing arrangements, doctrines or systems somehow fail to deliver important functions, and that 'failings' have to be 'corrected' in some way. The diagnosis and correction of failures and weaknesses become the main rationales for systemic policy interventions.

The market failures argument suggests that market mechanisms can lead to inefficient ('sub-optimal') resource allocation, such as in the case of negative externalities (e.g. pollution), public goods, positive externalities (e.g. innovation spillovers), or information and power asymmetries. It has become a central justification for environmental policy and innovation policy interventions, notably concerning non-renewable resources (Jaffe et al., 2005). Within a neoliberal tradition, it suggests that the supply of associated goods requires internalisation through market corrections mechanisms (e.g. pricing pollution costs, public R&D funding, government provision of public goods), justifying 'blanket' interventions at the level of sectors or entire economies.

Focussing on system weaknesses departs from the market failure logic, namely as it focusses on promoting or supporting specific options. Within such technology-oriented rationales, a common issue, notably at national level as governments strategically invest in specific technological domains, is related to desirability and political choice.

The structural system failures argument, rooted in evolutionary economics thinking about innovation systems (see also section 4.3.1), suggests that certain key *dynamic* processes (or functions) contributing to the development of new technologies may underperform, hence explaining deceiving performance at system level requiring alternatives to 'perfect market competition' (e.g. low level of cooperation and collaboration between actors, environmental regulation) (Weber and Rohracher, 2012). Four kinds of system failures are proposed (Helm and Mayer, 2016; Klein Woolthuis et al., 2005; Rip and Kemp, 1998; Weber and Rohracher, 2012) that prevent the development of path-breaking innovations: infrastructural failures (lack of physical and knowledge infrastructures), institutional failures and misalignments (shortcomings of formal institutions such as laws, regulations, and standards), interaction or network failures (limited interaction and knowledge exchange outside dominant networks), and capabilities failures (lack of appropriate competencies and resources).

Innovation systems approaches commonly refer to seven 'functions' that are crucial for successful performance (Bergek et al., 2008), whilst others prefer to discuss the relevance of 'activities' (Edquist, 2011). Importantly, the system failures argument suggests that system functions have emergent properties (Hekkert et al., 2007; Markard and Truffer, 2008): a) dynamic interactions between different elements and activities within systems are crucial, b) many actors interact in collective processes, and c) functions reinforce each other through cumulative causation – or fail to do so in less successful cases (Negro et al., 2007).

The transformational system failures argument further extends this logic by pointing to contextual aspects traditionally considered outside the remit of STI policy:

"Additional types of failures come into play, due to the broader scope of transformative change as compared to innovation performance only, and due to the long-term and fundamental character of the transformation process in question. These additional failure arguments point to a need for innovation policies that induce processes of transformative change and are thus strategic in nature." (Weber and Rohracher, 2012:1042)

More specifically, STI policy may require addressing failures concerning the directionality (e.g. the normative goal and long-term orientation of the transformation process), demand articulation, policy coordination and reflexivity of innovation activities and support (Scordato et al., 2017). The transformational system failures arguments features centrally within the TIS approach, which has largely been developed with reference to the identification of systems failures, including a number of structural weaknesses and "a wide variety of contextual factors leading to problems for TIS to emerge" (Markard et al., 2015:78).

Implications for transitions studies. Market, system and transformational failures argument provide important rationales for innovation and transitions policy, namely as they enable structured diagnoses of system weaknesses as explanations for difficulties to bring about transitions, and point to commonly neglected strategic objectives and enabling conditions. First, looking beyond market failures arguments can justify stronger involvement of governments and other strategic actors in stimulating alternatives (i.e. 'fostering players'), nurturing their development, and sustaining their accelerated diffusion (Langhelle et al., 2019). This is not proposed as something new, but as legitimate forms of governance. Furthermore, if strategic innovation policy is about selecting and stimulating *desirable* innovations (rather than relying on market allocation mechanisms or distributed agency), the governance of 'failure' also needs to become more central (Rip and Kemp, 1998). In this more strategic formulation of innovation policy, failure can be interpreted as a) an unsuccessful wager (i.e. betting on the wrong horse), b) a deficit of protection against selection pressures (i.e. not nurturing or shielding niches enough), or c) a result of overly prolonged protection (i.e. not weeding out innovation portfolios enough).

4.2.2. Policy failures as revealing dysfunctional governance

The literature on policy failures is concerned with understanding why and under which circumstances policy interventions are not implemented or do not lead to the intended effects. In other circumstances, especially pertaining to persistent and wicked problems, policy failures are mobilised as ways for explaining why policy problems are not met with adequate, effective or desirable solutions. Two related strands can be identified: 1) those concerned with defining and understanding different types of policy failures, and 2)

Table 2
Three frames, features and policy failure rationales for STI policy (EEA, 2019; Schot and Steinmueller, 2018a).

Framing	Key features	Policy rationale
Innovation for growth	Science and technology for growth, promoting production and consumption.	Responding to market failure: public good character of innovation necessitates state action.
National systems of innovation	Importance of knowledge systems in development and uptake of innovations.	Responding to system failure: maintaining competitiveness, coordinating system actors.
Transformative change	Alignment of social and environmental challenges with innovation objectives.	Responding to transformation failure: pathways, coordination domains, experimentation. learning.

those investigating policy processes, programmes and political activities.

Howlett (2012) provides an overview of policy approaches seeking to differentiate policy success from failure, including policy fiascos, policy accidents, policy disasters, policy catastrophes or policy anomalies. Other authors propose to situate policy failures within a broader variety of failures 'in the public sector', increasingly dramatic in their consequences and each linked to specific problem sources: policy failures relate to design problems, governance failures relate to political (e.g. legitimacy) or segmentation (e.g. coordination) problems, and state failures often relate to conflict or poverty problems (Peters, 2015).[3] Policy success/failure can be evaluated in terms of the achievement of policy objectives, targeted impacts, influence on problems addressed, the ability to act at all on a given problem, the degree of support from key groups, cost-benefit evaluations, and so on, but also on more comparative criteria including benchmarking against other contexts (which might be doing better), the policy innovativeness (e.g. the novelty of proposed responses), or normative judgements (e.g. right/wrong) (Howlett, 2012; McConnell, 2010). Clearly, policy failures are also multifarious, idiosyncratic and collectively constructed, but also largely dependent on contexts and processes (e.g. ongoing policy processes, political opportunities) and the particular nature of problems faced.

Moreover, there are different dimensions of policy failures to consider (also in the context of transition or innovation policy) (Howlett, 2012). Firstly, while most policy failures are 'unintentional', there are also failures "caused by ill will or malevolence" (Howlett, 2012:544). While these may be more prevalent in cases of corruption, governance and state failures, namely because it is assumed that policymakers tend to avoid blame, their possibility shouldn't be ruled out in the context of addressing major environmental, societal or technological challenges. Secondly, the 'avoidability' of failures characterises the extent to which governments can be expected to have foreseen, anticipated and/or corrected sources of problems and implementation issues with particular programmes or interventions, and the kinds of controls or corrective solutions that might have been set in motion to curtail such possibility. Avoidability may be lower under high uncertainty conditions, which displaces the problem of failure avoidance towards one of 'reasonable measures' and/or 'preparedness'. Further descriptive dimensions have been proposed by Howlett (2012) to capture different kinds of policy failures, namely their temporal and spatial magnitude (duration and extent) and their salience (visibility and intensity) (see Table 3).

Unintentional but avoidable policy failures may be attributable to poor design, knowledge deficits and information asymmetries (which are possibly increasing where governmental capacities have been eroded, or where issues are particularly complex), lack of ambition (itself linked to risk-aversion, or the result of tough political compromises), lack of imagination (which tends to produce incremental kinds of solutions), over-reliance on particular decision-making logics (e.g. reliance on market-based solutions or voluntary measures), or misfits between the kinds of problems faced and the governance arrangements in place (e.g. short-term rationalities facing long-term problems, specialised policy capacities facing multi-dimensional problem, risk-averse decision-making facing systemic problems). McConnell (2010) distinguishes three interacting strands: policy as process, programmes, and politics – in ways that echo John Kingdon's (1984) focus on problems, solutions and policy streams.[4] These different strands provide different levels of explanation and critical events for policy failures, and crucially failure in one strand may not be a failure in the other (e.g. local disruptions caused by the implementation of major public works for an urban transit scheme may lead to mayoral re-election failure, whilst the policy programme may have been very successful at delivering reliable public transport alternatives).

Finally, given the multidimensional, multi-causal and interpretive nature of policy failures it may be possible to see failure/success not as a binary opposition, but rather as a spectrum. Focussing specifically on crisis management initiatives as policy responses to a particular kind of problem characterised by high urgency, high levels of threat, significant uncertainty and public and political pressure, McConnell (2017) proposes an approach that considers failure/success as a continuum including 'durable success, 'conflicted success' and 'precarious failure' – suggesting that failure can only imply total abandonment, while there can be various shades of success. Furthermore, policy failures may be turned into opportunities for policy paradigm shifts or more transformational approaches (Newig et al., 2019), provided there is willingness, preparedness and ability to operate such shifts.

[3] We primarily focus on policy and governance failures because they are those most commonly mobilised within transitions studies, although state failures are very relevant notions for sustainability transitions, notably as long-term environmental threats (particularly climate change) are increasingly interpreted as concerns for the preservation human safety, livelihoods, and social justice – areas related to 'core state interests' (Dryzek et al., 2003).

[4] Failures at the level of policy processes can occur at any typical step in policy cycles (e.g. problem framing, examination of alternatives, decision). Failures at the level of policy programmes or policy initiatives are more specifically linked to matters of design and implementation. Failures at the level of politics concern the political repercussions and constraints upon policy development (including electoral, legitimacy and political delivery issues).

Table 3
Four principal types of avoidable policy failures: magnitude and salience in the unintentional failure space (Howlett, 2012).

		Magnitude (extent and duration)	
		High	Low
Salience (intensity and visibility)	High	Type I:major failure e.g. climate change (international treaty) policy failure	Type II: focused failure e.g. sports crowd control (riots) policy failure
	Low	Type III: diffuse failure e.g. anti-poverty policy failure	Type IV: minor failure e.g. policy service contract bid failure

Implications for transitions studies. The notion of policy failure has been picked up in relation to transitions challenges (Kern et al., 2014; Newig et al., 2019; Wood and Dow, 2011) as a means to problematise current and possible future directions for the governance of transformative change, or to explain the difficulties of introducing the kinds of change that may be needed to sustain radical innovations and transitions in practice (Schot and Steinmueller, 2018a; Weber and Rohracher, 2012). In light of the significant uncertainties, complexities and indeterminacies of transitions as process, it may be useful for the transitions community to engage with the notion of 'governance failure' (Peters, 2015) which chimes with the directionality and policy coordination failures proposed by Weber and Rohracher (2012), and with the observed erosion of the strategic state (Johnstone and Newell, 2017; Langhelle et al., 2019) and unequal vitality of the civic sector (Avelino and Wittmayer, 2016). Another area for further developments is that of comparative policy success/failure evaluations, whereby comparing policy outcomes across jurisdictions (Howlett, 2012) may uncover key conditions and determinants of success/failure. To some extent, the research community already engages with such methods, examining comparative success/failure in varied domains such as organic farming (Darnhofer et al., 2019), renewable energy (Cherp et al., 2017), electric mobility (Mazur et al., 2015), nuclear power (Sovacool and Valentine, 2012), and so on, but arguably not systematically enough.

4.2.3. Failures as opportunities for learning and failures to learn

At the level of individual organisations, networks or projects, failures are also framed as opportunities for learning and strategic renewal. Conversely, the lack of learning dispositions and failure-receptive interpretive frames tends to narrow down the opportunities to mobilise discrete failures as means to question and re-orient innovation strategies, hence limiting the potential for path-breaking innovation or adaptability in the context of uncertain environments. Indeed, engaging with path-breaking innovation is likely to involve significant deviation from current activities, to stretch existing capabilities and interpretive frames. It is inherently risky and likely to involve (some degree of) failure, hence challenging sense-making devices. Learning from failure entails three core activities and competencies: identifying failure, analysing failure, and deliberately experimenting (i.e. deliberately engaging with possible failure "for the express purpose of learning and innovating") (Cannon and Edmondson, 2005).

Experimentation, trial-and error, and learning from failed projects. Experimentation and trial-and-error problem-solving are important processes for the development of new products and services (Thomke et al., 1998), and may be particularly relevant to support radical innovation in the context of transitions (Hoogma, 2000; Schot and Geels, 2008; Sengers et al., 2019).

In an organisational context, controlled experimentation about technical factors tends to be constrained by cost-effectiveness and speed of the learning process (Thomke et al., 1998): unsuccessful trials are costly and oriented towards a maximisation of results. So, detecting and making the most of failed trials, such as in serial experimentation strategies oriented towards narrowing down the solution space (rather than 'testing' specific solutions) can be an effective strategy. Experiments (and the possibility of failed 'trials') may also be oriented towards non-technical aspects such as markets, user acceptance, and so on. In the context of rapidly changing environments, organisational search processes may benefit from being oriented towards discovery. Discovery-driven planning requires an ability to analyse implications of failure with experiments in terms of new or 'yet unknown' questions (Chesbrough, 2010), which may for instance trigger the search for radically different business models or innovation trajectories (Elmquist and Le Masson, 2009).

Maidique and Zirger (1985) coined the phrase 'learning by failing" to capture different kinds of organisational learning occurring in the wake of failed project, which can a) "act as important probes into user space" and hence catalyse major reorientations, or b) support the identification of weak links within organisations and strengthen them against similar failure patterns. They further suggest that sequences of projects ('product families') provide a more relevant entry point for learning – denoting a significant reframing of analysis and action rationales. The potential for learning by failing justifies approaches that tolerate failure (e.g. by complementing project-oriented approach with a longer view of process), value variety creation (e.g. by developing portfolios of options and solutions), and nurture a capacity for learning and knowledge circulation.

In the context of socio-technical niche development (see also section 4.3.3), experimentation is 1) broader in scope (and hence multi-dimensional) and 2) more distributed (and hence difficult to coordinate) – but likewise requires a reframing to capture sequences and contexts. This has implications concerning how failures are perceived and what is made of them, because these may be less readily identifiable, harder to attribute to specific causes, and because the transmission of 'failure knowledge' is likely more difficult in loose or informal networks and across diverse actors in the absence of adequate knowledge infrastructures and emergent forms of 'coordination'. Effective niche building nonetheless requires ways to learn about 'what works' and 'what doesn't work'. Within the emerging community energy niche in the UK, for instance (Seyfang et al., 2014) observed that while groups had high abilities for dealing with and learning from failure *within* projects, this did not easily translate into high degrees of learning between community groups and even less so with intermediaries supposed to articulate and lessons and support their circulation.

Failing to learn, adaptive management and re-orientation. While failure may be costly, failing to learn and adapt can be deadly for organisations, particularly in the context of rapid changes in technological, market, or institutional contexts.

Learning and adaptability to changing, unfamiliar or unexpected circumstances are seen as important determinants of success in the strategic management and organisational literatures (Chesbrough, 2010). But learning is not a straightforward organisational ability, namely because organisations often derive their effectiveness and stability from operating within institutionalised templates (Greenwood and Hinings, 1988; Mintzberg et al., 1998), routines (Dosi, 1982; Nelson and Winter, 1982) and cognitive beliefs (Barr et al., 1992; Tripsas and Gavetti, 2000), as well as financial and material commitments to established activities. The ability to change deep-seated sets of rules and interpretive frames is referred to as second-order or double loop learning (Argyris, 1976; Mintzberg et al., 1998; Nystrom and Starbuck, 1984). Second-order learning may require a heightened sense of urgency stimulated by shocks and crises (Taylor, 1982; Turnheim and Geels, 2013), the involvement of broad networks of actors including relative outsiders (Schot and Geels, 2008), an experimental mindset (Chesbrough, 2010), and strategic agility or organisational ambidexterity (O'Reilly and Tushman, 2013). Further, organisational failure can be mobilised as an important source of strategic learning (Bourgeois and Eisenhardt, 1988; Cannon and Edmondson, 2005; Shepherd and Kuratko, 2009), which calls for deeper reflections on preparedness to the managerial and governance challenges of dealing with failure and obsolescence. Learning to learn from failure requires the development of failure-tolerant organisational cultures and practices (Alexander et al., 2015).

Implications for transitions studies. Strategic experimentation and collective learning processes in niches are key features of SNM approaches (Geels and Deuten, 2006; Raven et al., 2010; Schot and Geels, 2008; Smith and Raven, 2012; Turnheim and Geels, 2019). SNM builds on the notion of serial experimentation through sequences of projects, which may be undertaken by a variety of actors within a forming socio-technical niche. Key mechanisms include a) knowledge codification, accumulation and circulation in communities of practice, b) the development of networks of actors, and c) the sharpening of visions and expectations. In this context, failures or difficulties encountered in discrete projects are valuable insofar as they are taken up as opportunities to orient collective search and discovery processes. Beyond niches and early phases of socio-technical developments, there is also growing recognition of the importance of addressing opportunities for learning from failure at the level of existing organisations, structures, practices, and systems. The literature on destabilisation and decline links organisational and industry failure to various forms of inertia, i.e. persistence with familiar (but obsolete) practices and strategic orientations, in the context of growing challenges and mismatches with changing environments and/or growing internal tensions (see section 4.3.2). In this context, Van Mierlo and Beers (2018) interestingly suggest that learning in the context of destabilisation may be a two-way process involving 1) 'unlearning' (to do away with the old and support the discontinuation of unsustainable systems), and 2) resistive learning ("learning about how to resist change, more specifically to hinder transition efforts and block a transition pathway"). Furthermore, and applied at the broader level of institutions, Newig et al. (2019) examine five archetypical 'productive functions' of institutional failure as opportunities for structural change.

4.3. Broadening and contextualising processual accounts of failures

Perspectives considered in this section are primarily focus on failure as a process in the context of broader dynamics, involving different actors, systems and institutions that call for close examination, and particularly concerned with framing failure as an inherent part of innovation or transition journeys – although it is rarely the primary focus of analysis.

4.3.1. Evolutionary failures as vital sources of change

In opposition to perspectives framing failure as problems to avoid or curtail (see sections 4.1.1,4.1.2, 4.2.1, 4.2.2), there is another view according to which failures are inevitable, necessary, productive, or even vital drivers of change.

Evolutionary perspectives on change ascribe an important role to failure and problems as a) triggering the search for new solutions or entirely new trajectories, b) the inevitable flipside of selection processes by which dominant designs emerge (i.e. failing organisations and designs are 'selected out'), and c) sources of continuous change (pressures to adapt to changing selection environments). Evolutionary metaphors focussed on innovation and technology emerged as alternatives to linear views, in order to emphasise the open, processual, uncertain nature of technological development as marked by "surprise, change, mutation, bifurcation, feedback and crises" (Freeman and Louça, 2001) and unpredictability of scale, speed, scope, and direction of change. Given inherent uncertainty and unpredictability, evolutionary approaches seek to identify patterns of change (e.g. trajectories, configurations and long-term fluctuations). Of particular interest are 1) the alternation of continuous change and discontinuities, 2) the dialogic nature of creative and destructive dynamics, and 3) forms of adaptation to changing environments and discontinuities. Evolutionary metaphors are found in various strands of research underpinning transitions studies. They constitute important conceptual roots and building blocks with significant lessons related to failure.

Macro-approaches (e.g. population ecology and industry life cycle) examine entire sectors or industries as populations of firms, and are primarily interested in the rates of entry, survival and decline within populations of firms within an industry (Hannan and Freeman, 1977; Volberda and Lewin, 2003). Organisational mortality is interpreted as an outcome of selection pressures generating space for new entrants – so 'failure' fulfils a productive role on a collective level. However, organisational exposure to failure risks is variable, because organisations continuously change, and because organisational inertia is itself an outcome of selection pressures (Hannan and Freeman, 1984). So, an ability to avoid failure through also produces concentration (selecting firms out) and hampers innovativeness in later stages of industry maturation (Klepper, 1996). Risk of failure may also be more important in formative years of industry creation (Aldrich and Fiol, 1994).

Micro-approaches (e.g. organisational change, strategic management) look at organisational failure from the perspective of failed adaptation to changing environments, with a specific focus on the conditions, organisational attributes and strategies more favourable to navigating different kinds of change environments (Bourgeois and Eisenhardt, 1988) and re-orienting existing activities and structures (Henderson and Clark, 1990). Engaging with radical innovation may be necessary (to avoid failure through obsolescence) but also demanding: it requires specific resources, competences and skillsets (Teece, 1986), and dedicated managerial ability for sensing changing environments and adapting strategies accordingly (e.g. exploration vs. exploitation activities) (Tushman and Anderson, 1986; Tushman and Romanelli, 1985). Failure and success with innovation also fundamentally depends on the field-centrality of an organisation (e.g. degree of commitment to regime rules) and the kind of strategic innovation process pursued (e.g. disruptive or sustaining) (Bower and Christensen, 1995).

Co-evolutionary approaches (Leonard-Barton, 1988; McCarthy et al., 2010; Volberda and Lewin, 2003) are broader in scope (they extend beyond economic, organisational and technological dynamics). They seek to dynamically characterise industry environments and organisational strategies in the face of different kinds of change. Applied to innovation in organisational fields, co-evolutionary approaches emphasise dynamics of mutual adaptations or coupling (e.g. of firms/environments, supply/demand, technology/users, actors/institutions) over time, and point to the multi-dimensional and contingent nature of such couplings.

The study of techno-economic paradigms and revolutionary change (Freeman and Louça, 2001; Freeman and Perez, 1988; Perez, 2010), which has a co-evolutionary flavour, adopts a wider analytical lens to focus on major technological revolutions and underlying paradigms, explaining long-term economic fluctuations and structural change in terms of the interaction and alignment of techno-economic dynamics (technological innovation, economic growth, business cycles) with social, political and institutional dynamics.

Conversely, lack of alignment can lead to stagnation or breakdown. The study of techno-economic paradigm shifts assigns an important role to structural system breakdowns and crises, suggesting that a) industry growth and boom phases are contrasted with periods of instability and low investment confidence, b) techno-economic paradigm shifts can generate significant crises of adjustment on a wide scale, as new technologies replace old ones and make certain business activities obsolete – temporarily destabilising investment patterns (Freeman and Perez, 1988) in 'creative gales of destruction' as coined by Schumpeter (Fagerberg, 2003), c) 'great surges of development' involve turbulent and unsettled times (imbalances, tensions, polarisation) where incumbent industries, technologies, and skills become outdated and obsolete (Perez, 2010), d) crises, breakdowns and failures are seen as cumulative processes in which negative feedbacks ('downward spirals', 'vicious circles') are crucial amplification mechanisms that can lead to runaway dynamics, and e) crises, breakdowns and failures can play a generative role, if structural misalignments are addressed substantially at the level of deep structures.

Implications for transitions studies. Transitions research broadly ascribes to a co-evolutionary understanding (i.e. selection and variation environments are dynamically interlinked) (Geels, 2002b; Raven and Verbong, 2004). Importantly, co-evolutionary dynamics within transitions frameworks are seen as mediated or modulated by (networks of) actors, institutions, and cumulative technological trajectories (Rip and Kemp, 1998). Failure is inherent to (co-)evolutionary processes, but also often treaded as residual. Two broad kinds of co-evolutionary failures can be identified: 1) failures (of existing systems, configurations or organisations) to adapt to changing environments, and 2) failures to introduce changes (in systems, configurations or organisations) within existing environments. Process, sequencing, and timing are crucial to failure, as they produce different patterns including gradual failure, cascading failure, and so on.

Furthermore, the interest of transitions studies in the temporal and processual character of socio-technical change leads to the identification of ideal-typical stages (e.g. early development, take-off or acceleration, stabilization or maturity) which may be linked to a variety of types of failures and failings. So, it may be possible to distinguish early failures from maturity failures, as well as failures in times of relative stability ('cold periods') and periods of relative discontinuity ('hot periods'). The notion of socio-technical niche, for instance, relates to exceptional socio-technical spaces (Smith and Raven, 2012) wherein the likelihood of evolutionary failures (i.e. linked to overbearing external selection pressures) is reduced through shielding mechanisms.

Lastly, transitions research also ascribes to the potentially productive role of failures, breakdowns and crises, notably in terms of opening up opportunity structures (Newig et al., 2019; Turnheim and Geels, 2013) (see section 4.3.2) or triggering new phases in search paths (see section 4.3.3).

4.3.2. Transition failures as related to dynamics of stagnation, destabilisation and renewal

Transitions studies are primarily concerned with innovation and the emergence of novelty, in the context of strong inertial forces of existing systems and practices. Recently, the importance of studying the 'flipside' of transitions has emerged as an important focus: sources of lock-in (Arthur, 1989; Klitkou et al., 2015; Seto et al., 2016; Unruh, 2000), active resistance to change (Bergek et al., 2013; Geels, 2014; Hess, 2014), dynamics of destabilisation and decline (Turnheim and Geels, 2013), or deliberate discontinuation (Stegmaier et al., 2014).

Within lifecycle approaches, dynamics of stagnation, destabilisation and decline (whether of organisations, industries or entire systems) are seen as later stages of development, following from their emergence, development and stabilisation. Studies of Large Technological Systems (LTS) interpret system decline as a stage in which system growth slows down, stagnates and may experience displacement or substitution by another system. Importantly, such decline can be relative (Sovacool et al., 2018). In cases of relative decline, systems do not entirely cease to exist and may indeed continue catering to a significant number of users, as with the Amtrak rail in the US (Minn, 2016) or the shrinking importance of coal in power generation in a number of European countries. Other systems may decline entirely, like electric streetcars and trolleys (trams) in the US and in European cities to make way for motorised transport. The erosion of trams in Western European cities was at first a gradual consequence of declining interest and maintenance (from the 1930s), and accelerated with the rapid expansion of car use and active digging up of the infrastructure (tracks and wires) in the 1950s-60 s. Ironically, many European cities have since experienced a renewed interest for 'modern tramways' and 'light rail' (Turnheim and Geels, 2019).

Decline may follow different patterns and speeds but tends to be associated with an underlying erosion of significance (societal, political, market), resources (financial, material, infrastructure, influence) and user base. Such gradual erosion processes generate feedback loops that can lead decline to spiral out of control in accelerated processes, as has been observed in organisational failure and decline (Hambrick and D'Aveni, 1988; Weitzel and Jonsson, 1989), or the decline of institutional structures (Newig et al., 2019) and even entire industries (Turnheim and Geels, 2012). In the context of large firm failures, Hambrick and D'Aveni (1988) link corporate failures to various forms of inertia, an inability to change despite "very substantial period[s] of warning, and hence of potential turnaround, before they fail", and that negative feedback loops. So, decline and failure are both the outcome of gradual erosion and one of its many antecedents.

While it may have some features of a self-fulfilling prophecy, decline is not inevitable or irreversible, and may also be reverted (i.e. avoided) and in some cases formerly outdated systems or solutions may be 'resurrected' (Goldenberg et al., 2004; Passalacqua, 2011) – hence blurring observations of 'decline' or 'failure'. Crucial to averting, avoiding or minimising the consequences of stagnation and decline arising from destabilisation is the active management and governance of such processes.

Industry destabilisation (of organisations or industries) can indeed lead to decline, re-orientation, or re-creation pathways (Turnheim and Geels, 2013). The car industry, for instance, while experiencing growing challenges related to road safety (1950s-70 s), first refuted problems and actively lobbied to minimise their threats, but later managed to adapt to such pressures through technical safety improvements (e.g. seat belts, airbags) and regulation (e.g. speed limitations) (Geels and Penna, 2015). Faced with air pollution and climate change challenges, the car industry also partly managed to deflect problems and re-orient itself through incremental design improvements (e.g. catalytic converters, fuel efficiency), and later by advocating 'greener pathways' such as alternative engines (Penna and Geels, 2015), and may yet be facing a new phase of potential destabilisation or adaptation (Hoffmann et al., 2017). While active intervention to avoid decline may lead to entirely new paths, short-sighted strategies can lead to only temporary deflection of problems. Such strategies, particularly salient with large technical systems that come to be perceived as 'too big to fail', can however potentially heighten the risk of subsequent destabilisation and dramatic decline, as has been experienced with UK coal mining in the 1980s, following a long period of artificial support with only limited attention to the development of alternatives (Turnheim and Geels, 2013). In light of the substantial economic, social and political consequences of unmanaged decline, anticipating emerging patterns of destabilisation and decline appear as important requirements for the governance of transitions.

Implications for transition studies. Focussing on lock-in, resistance to change and destabilisation offers a complementary explanation of transition failure. Instead of interpreting transition failure as disappointment with emerging dynamics, it focusses on dynamics of continuity (Wells and Nieuwenhuis, 2012) and path insistence as failure and unwillingness to change existing systems. Conversely, understanding the persistence and obduracy of existing systems, despite strong forces of change, might benefit from being framed as a particular kind of 'transition failure' related to the near-impossibility of operating fundamental changes. The lack of systemic responses to what are perceived as existential system failures relates to a) the sheer size and societal relevance of (socio-) technical systems, infrastructure and industries seen as 'too big/important to fail'; b) established socio-technical trajectories characterised by lock-ins, inertia and resistance to change (Arthur, 1989; Klitkou et al., 2015; Seto et al., 2016; Unruh, 2000), even when motives appear compelling and existential; c) the vested interests of powerful actors reinforcing lock-ins through the minimisation of problems and pressures (Geels, 2014; Hess, 2014; Penna and Geels, 2012; Roberts et al., 2018; Wells and Nieuwenhuis, 2012) and orienting change strategies towards preserving paths of incremental change; d) organisational, reputational and emotional commitments contributing to a fear of failure that tends to cripple and lead to risk-aversion in organisations, governance, and beyond (Howlett, 2014; Meadowcroft, 2007; Pettersen and Schulman, 2016); e) a lack of imagination about alternative courses of action (Turnheim and Nykvist, 2019).

4.3.3. Radical innovation failures as contextualised along socio-technical trajectories

Radical innovation processes are inherently failure prone. Beyond technical and engineering challenges with specific products, devices and systems, there are different types or explanations for failure with the development of innovations and socio-technical trajectories. We here discuss the importance of embeddedness and process.

Alignment and embeddedness in wider structures. Niche-innovation implementation and commercialization failures (Negro et al., 2007; Raven and Verbong, 2004; Smith et al., 2014), particularly with radical innovations, have been linked to difficulties developing markets and generating demand, but also mismatches between innovation system activities and institutional frameworks. Raven and Verbong (2004) suggest that the failed implementation of particular technologies, when not primarily linked to inherent technical deficiencies, points to the importance of context, rule-sets and interests involved. They attribute the difficulties developing central manure processing in the Netherlands, in spite of a strong alliance of engineers and politicians, to 1) the neglect to involve a key actor group (farmers) in the process, 2) a lack of positive expectations for development, and 3) conflicting norms and regulations at various levels.

Failures and disappointments with innovation and socio-technical developments are inherently tied to mismatches with selection environments, which are particularly acute for sustainability innovation and transitions for which there is a 'dual challenge' to develop novelty on technical dimensions (e.g. technologies, infrastructure, recombinations) along with changes in the criteria by which innovations are appreciated (e.g. norms, values, regulations, user preferences) (Kemp and Van Lente, 2011). So long as the prevailing selection criteria and institutional settings are not aligned with sustainability objectives, niche-innovations are likely to face 'unfriendly environments' and hence require some form of protection and nurturing (in niches where mainstream selection environments may be less 'unfriendly'), and empowerment strategies (Raven et al., 2016; Verhees et al., 2013).

The importance of process. Linking back to the temporal dimension of embeddedness, failure with innovations and transitions can be seen as related to a deficit of embedd*ing*: innovation and transition failures are failures to embed and become embedded. Innovations do not become embedded in wider structures overnight; they *become* embedded. Embedding requires work and is a contingent process. Innovation and transitions are inherently processual and uncertain (failure is always looming). Studying radical innovation calls for longitudinal analysis of development trajectories and field-level dynamics so as to see beyond particular setbacks and challenges, failures and 'burnouts' experienced by innovation pioneers (Olleros, 1986).

Studies of niche-innovation implementation failures further point to the important of developmental processes, which may follow non-linear patterns with ups and downs (Geels and Raven, 2006), hypes and disappointments – namely as failure may become manifest as and reinforced by disappointments, delays or abandonment (Budde et al., 2015; Konrad et al., 2012; Ruef and Markard, 2010) following from hype periods where expectations may be artificially inflated. The 'Better Place' case of failed EV development project in Denmark and Israel is a case in point, for which tremendous entrepreneurial and fundraising success, namely bolstered by political support and commitment to solutions to energy security, rapidly turned into failure when policy support dwindled (Cohen and Naor, 2017). Failed expectations (disappointments) with radical innovation are linked to an overemphasis on R&D and grand visions (over market development, diffusion, and embedding processes) (Suurs et al., 2010), downplaying costs and neglecting competing alternatives or exaggerating abilities and control (Lovallo and Kahneman, 2003), an inflation of promises or hype-disappointment cycles (Konrad et al., 2012), or a neglect of other TIS functions (Bos et al., 2016).

While such disappointments are often negative for the development of innovation fields (e.g. translating into reduced attention and interest, legitimacy losses, reputational damages for proponents, declining resource commitments), they do not necessarily lead to a full delegitimation of innovations, particularly when stable positive framings and emerging institutions provide continuity (Ruef and Markard, 2010). Furthermore, Raven and Verbong (2004) remind us that project failures can disproportionally contribute to learning and knowledge development within niches.

Implications for transitions studies. The notion of embeddedness, which qualifies interdependent linkages and influences between forms of action and wider structures, provides a complementary perspective on the importance of mutual alignment with external conditions to explain why innovations succeed or fail in particular contexts (Boschma et al., 2002; Hess, 2004; Rip, 2012). The embeddedness of innovations in wider contexts can be understood as occurring on various dimensions, including market, social, political, technological, spatial and temporal. The spatial dimension of innovation embeddedness (Coenen et al., 2012) is particularly relevant, as it enables to understand why particular transitions may fail in certain places when they might be successful elsewhere (geographical contingency), but also how they spatial and material opportunities influence transition features (emergent opportunities and style variations), their success and failure. Chlebna and Simmie (2018), for instance, compare onshore wind path development in Germany and the UK and explain the abandonment in the UK in relation to institutional arrangements and changing circumstances. Sovacool (2018) similarly looks at the failure of an identically designed program to promote solar home systems in Indonesia contrasted with the success of another program in Sri Lanka, also connected with changing political and economic environments as well as different regimes of governance.

Radical innovation and socio-technical path development proceeds through erratic journeys (Garud and Gehman, 2012; Kemp et al., 2001; van de Ven et al., 1999) ridden with punctual troubles and failures, which are often key to future developments. The 'troublesome' development and diffusion of radical innovations (Negro et al., 2012) can in some cases lead to path development failure (Negro et al., 2007) and dead-ends (Geels, 2005), whilst in other cases it may actively contribute to niche accumulation, recombinant innovation, hybridisation, innovation cascades (Raven, 2007), or even re-orient the direction of search towards radically different development paths.

Regardless of their contribution to longer-term trajectories, however, innovation failures are extremely trying for the actors involved (bankruptcies, disillusionment, irreversible reorientation of commitments and resources) and may have lasting effects on the wider networks supporting their development.

5. Discussion: what can be learned from failure?

We opened by identifying a lack of systematic research on failure in transitions studies. We here discuss our findings in relation to our two first research questions. To begin this synthesis, Table 4 offers some possible recommendations to counter the biases discussed in Section 3:

These four kinds of bias, still apparent through the field, are however benefiting from significant adjustments, namely concerning a) reduced expectations set on single projects (Hoogma et al., 2002) or niches, b) a stronger recognition that change and stability dynamics are influenced by multiple levels of structuration (Diaz et al., 2013; Hess, 2016; Ingram et al., 2015; Verhees et al., 2013), c) a move towards the recognition of multiple developmental trajectories and pathways (Geels and Schot, 2007; Raven, 2006; Rosenbloom,

Table 4
Overview of novelty biases and possible courses of action.

Kind of bias	Manifestation / motive	Recommendations
Selection bias	Tendency to focus on cases of realised or desirable transitions rather than failed or undesirable transitions	Purposely select failure cases and engage with comparisons of success and failure
Cognitive bias	Difficulties perceiving, observing or gaining access to failure events	Legitimize (and incentivize with resources) the study of failure within the community; appreciate the complexity of failure
Interpretive bias	Focus on telling heroic stories of emergence and change, overlooking more mundane occurrence of difficulties	Pay symmetric attention to failures, setbacks, challenges within cases; Revisit classic cases from failure perspective (e.g. looking at paths not taken)
Prescription bias	Recommendations emphasising difficulties, challenges and uncertainties seen as problematic	Orient and calibrate policy mixes and governance towards learning from failure

2017; Smith et al., 2005; Turnheim and Nykvist, 2019), d) a stronger emphasis on stories with twists, turns, detours, deviations and difficulties (den Hartog et al., 2018; Farla et al., 2012; Fressoli et al., 2014; Garud and Gehman, 2012; Nykvist, 2013; Smink et al., 2015) – including a focus on failed transitions attempts, and e) increasing subtlety as to the messages and prescriptions brought forward in policy settings. Focussing more explicitly on transitions failures, path creation difficulties, and paths not taken provides further fruitful avenues for addressing such pitfalls. In order to adequately account for the development of technologies and innovation journeys, "impartiality with regard to successful and unsuccessful developments is necessary; otherwise, analysts end up with a distorted linear picture of what has happened" (Rip and Kemp, 1998:358). So, it is as important to analyse paths taken as it is paths not taken, as well as the knock-on effect of interrupted or stunted path on realised innovation trajectories. In other words, failure may be as informative as success. In practice, however, there is still a looming bias towards accounts of successes.

Concerning the range of available takes on failures, section 4 has discussed a number of perspectives and conceptual building blocks, confirming that failure and uncertainty are important concerns and rationales for transitions research, touched upon by various strands and in related fields, but rarely are the central focal object of study. As Table 1 also highlights, the nine perspectives identified offer a rich variety of analytical entry points and explanatory foci for better understanding failure. It also points to distinct conceptualisations of failure, suggesting varying degrees of ontological compatibility, with perspectives related to a mosaic of literatures (e.g. economics, organisational change, policy studies, sociology, history), as evidenced by the last column of Table 1.

Furthermore, in our presentation and classification of nine perspectives dealing with failure within and around transitions studies, we have privileged a combination of thematic and analytical criteria (focal analytical unit, system boundaries, analytical levels, rationale, analytical style), leading to the identification of three 'families' of perspectives. We have also noted inherent ambiguities and overlaps in any classification attempt. For each of these perspectives, we have discussed some core implications for transitions studies in ways more cognisant of the theme of failure. Although we have organised our findings on failure along fairly stylised 'families' of perspectives spanning discrete failures, systemic failings, and processual accounts, these categories of course interrelate, and can also mutually shape each other. Fig. 1 visually synthesizes our arguments by showing how failures are perceived within the different literatures, and how the dynamics of failure can interact in ways across those families of perspectives.

In order to further make sense of the nine identified perspectives on failure, which we have ordered by privileging analytical unit and core framings, it is worthwhile to discuss them in terms of their explanatory focus (column 3 in Table 1). Two further dimensions emerge that speak directly to core puzzles and analytical orientations within transitions studies: 1) a tension between processes of emergence (merely introducing an innovation or technology, adapting it to society) *and* processes of transformation as the object of change (attempting to radically alter society, or adapting society to the innovation) and 2) a tension between micro- *and* macro-perspectives as primary orientations for explanation. Fig. 2 plots these dimensions on two axes and positions each perspective with regards to these tensions, further illustrating the richness of the perspectives identified (a variety of analytical entry points and stances are available) and the ambiguity of any classification attempt (different clusters emerge, while certain perspectives straddle these tensions). It reveals possible alignments between perspectives that can support conceptualisations of failure.

The vertical axis relates to the focus of change considered, whether this concerns the introduction of (radical) novelty and failures thereof, or the introduction of significant changes in existing systems and failures thereof. Accordingly, it is possible to distinguish perspectives focussing on failed attempts at fostering the emergence, development and stabilisation of novelty (innovation failures; bottom quadrants) from those focussing on the adaptation or change of existing system (transformation failures; top quadrants). Admittedly, a number of perspectives straddle this dimension, namely those classified as 'systemic failings accounts' which tend to

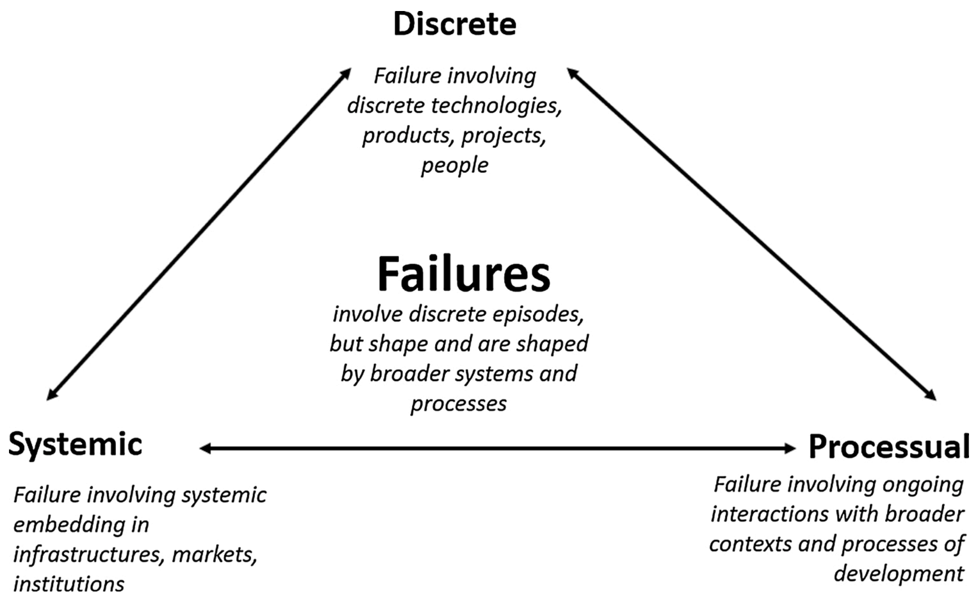

Fig. 1. The interconnected nature of perspectives on socio-technical failures. Source: Authors.

explain failure to introduce (innovation, policy, cognitive) change as resulting from systemic deficits also calling for adapting existing systems) and the 'hardcore' of transitions approaches (radical innovation and transition failures) which explain radical innovation and systemic change processes as interrelated phenomena.

The horizontal axis relates to the orientation of explanation, whether this primarily results from an inward-focus whereby perspectives zoom in cases of failure to explain their particular circumstances (micro-perspectives; left quadrants), or from an outward-focus whereby perspectives mobilise cases of failure to seek out more universal forms of explanation (macro-perspectives; right quadrants). Unsurprisingly, perspectives focused on individual episodes of failure (discrete accounts of failure), often with minute detail, tend to mobilise micro-approaches, while those focussed on failure more residually as a means for explaining broader systemic features and macro dynamics (evolutionary, policy and generalised systemic failures) are located to the right. Other perspectives operate at a meso-level and engage in both zooming in and zooming out (e.g. transition failures, radical innovation failures and learning approaches).

Again, owing to the importance of explaining transitions and transformation as resulting from multi-level processes and the combination of structural and enacted sources of continuity/change, it is not fully surprising that the 'hardcore' of transitions approaches (radical innovation and transition failures) straddle micro- and macro-orientations to explanation. Learning approaches to failure (learning to fail and failure to learn) appear as particularly interesting, insofar as they offer insights and explanatory modes relevant to understanding both the (failed) stabilisation of novelty and the (failed) change of existing systems and are derived from a sustained commitment to reframing the relevant analytical level to make sense of failures, setbacks, surprises or disappointments as a means for navigating turbulent and uncertain times.

6. Conclusion: can transitions research engage more systematically with failure?

The transitions studies field is operating a welcome renewal of its core concepts and analytical devices, notably towards more systematic comparisons and the refinement of overly stylised accounts. This offers significant scope for richer accounts of themes related to failure, notably as increasing emphasis is set on politics, uncertainty, conflicts, tensions, heterogeneity, and sources of inertia. So, there is significant potential and fertile ground for further attention to the role of failure within transitions studies, which we have sought to discuss in detail. Conceptually and analytically, transitions studies is inherently attentive to long-term co-evolutionary processes, the influence of context, the importance of multiple and changing units of analysis, complexity, challenges and tensions. Empirically, the focus on rich longitudinal case studies as privileged research method provides significant scope for delving into the role of messiness, deviations, twists and turns along failure-prone and -laden trajectories. We see four main ways in which transitions studies may take up the role of failures in transitions studies and their governance more seriously.

Firstly, we find that there is a need to further legitimise the study of failure within transitions studies, and to maintain an open outlook as to what such research may produce. Indeed, while we have observed that failures can be an object of study in and for itself, we have also seen that this is rarely a primary focus. Taking this challenge up entails deepening existing conceptual understandings of failure(s) and deriving operational ways of studying them within a transition context. Furthermore, there is a need for a phenomenology of failures that can more systematically attend to the core distinguishing features (e.g. magnitude, salience, frequency), core causal explanations, conditions, processes and patterns. 'Failed transitions' case studies may examine more in-depth particular paths not taken (e.g. electric cars at the beginning of the twentieth century), revisit classical cases by focussing more specifically on the failures that may have forced the emergence of novel paths, or develop counterfactual analyses. We are convinced that engaging with the 'book of blots' (Gooday, 1998) of failed transitions and the 'transitions that never happened' is a constructive undertaking, but this also requires that research funding streams are oriented towards such efforts for which immediate results may be less tangible.

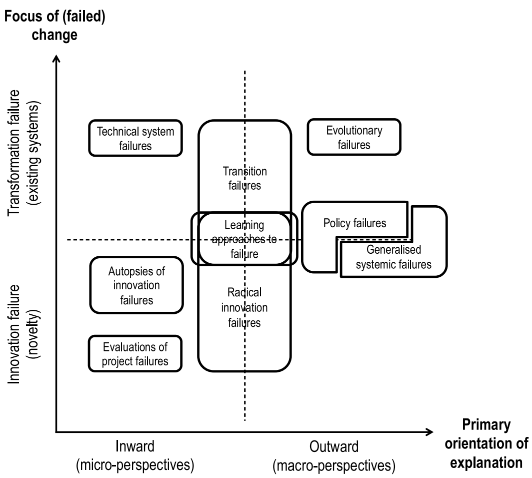

Fig. 2. Putting perspectives on failure in perspective. Source: Authors.

Secondly, taking up the symmetry principle put forward by constructivist sociologists and historians of technology might lead to “a more realistic view of how technology developed” (Braun, 1992). But how would this work in practice in the context of transitions studies and how might failure enrich transitions studies? One possible step involves a quest for rebalancing the empirical base of transitions studies, which is made up of a substantial collection of in-depth cases (historical and contemporary) largely tilting towards ‘realised transitions’ in favour of more accounts of stability in spite of change attempts. For instance, there have been recent pushes in favour of a more symmetrical analysis of change and stability in transition (Turnheim and Geels, 2012; van der Vleuten and Högselius, 2012; Wells and Nieuwenhuis, 2012), which appear relevant although it is unclear how far strict symmetry should be pursued. Taking the idiosyncratic and constructed nature of failure seriously would also mean engaging more firmly with the interpretive flexibility of so-called ‘successful’ or ‘realised’ transitions. As a consequence, rather than focussing on delimiting inherently contested instances of failure, it may be more relevant to intensify research efforts on the processes, series of events, contexts and circumstances that contribute to stunted paths, unexpected twists and turns observed along innovation journeys.

Further, following a stronger symmetry principle would require revisiting existing conceptual lenses and analytical constructs in light of a failure-oriented perspective of transitions, particularly given that “a determined focus on failures provides a different perspective, a new perception of technological change” (Bauer, 2014). In terms of empirical and analytical strategies, a possible direction is to purposely select cases in which transitions have not happened or have been disappointing (Dewald and Achternbosch, 2016; Johnson et al., 2016; Wells and Nieuwenhuis, 2012). A more comparative direction is to simply compare and contrast relative successes and failures with similar innovations or transitions across different contexts, which may lead to richer explanations for failure.

Thirdly, the research community needs to better engage with, open up, and even welcome complexity, or at least become more aware about uncertainty and the unknowability of outcomes. Stirling (2010) argues that experts must look beyond knowledge about risks and their management towards forms of knowledge that engage constructively with inherent ambiguity, uncertainty of socio-technical processes and possible sources of ignorance. A practical way to achieve this is to embed plural and conditional aspects into the research process itself, and to mobilise participatory, deliberative methods that privilege actor interaction and do not suppress dissensus and sources of tension. Such approaches can reveal, rather than obscure, uncertainty and complexity, as well as stimulate reflexivity about sources of ignorance. Stirling also explicitly notes such an approach “would help avoid erroneous ‘one-track,’ ‘race to the future’ visions of progress” that are also prone to failure. McGoey (2012) goes further in arguing for a “sociology of ignorance” to better comprehend how knowledge claims are deflected or obscured, and how strategic unknowns can be harnessed as a resource.

Fourth, and finally, transitions governance needs to better tolerate and even encourage engagement with failure in forward-looking programmes and orientations. As Schot and Steinmueller (2018b:1584) write, “[t]ransformative innovation policies need flexibility, experimentation, acceptance of failure.” Governance must become more attuned to surprises and unexpected consequences of transitions interventions, including failure. Concerning the governance of path creation, portfolio approaches that are oriented towards the generation of requisite variety and privilege the long-term development of trajectories (over short-term possibility of failure) could assist with this task, alongside adaptive governance (ongoing evaluation, learning, strategic intervention) that is cognisant of unavoidable degrees of failure. Concerning the conditions and contexts that may enable transitions and transformations, there is a need to uphold a strong view on the open-ended, undetermined and inherently uncertain nature of socio-technical change and its possible directions, in line with the commitment of learning approaches. This has led Kuhlmann and Rip (2018) to suggest an important role for ‘tentative’ forms of governance and policy implementation that are “aim[ed] at creating spaces for probing and learning instead of stipulating options for actors, institutions, and processes” or pursing ‘definitive’ orientations and means (Kuhlmann et al., 2019). Engaging more deeply and reflexively with the role, importance, and inevitability of failure in the context of transitions appears relevant to ongoing reflections about transitions governance.

Taken together, these four proposed directions—legitimizing failure, practicing symmetry, welcoming complexity, and embracing failure within policy and governance—would help ensure that rather than being consciously or even unconsciously stigmatised, failure itself is transformed from a pejorative to a compellingly performative part of transitions themselves and the scholarship that accompanies them.

Declaration of Competing Interest

The authors report no declarations of interest.

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