Global Sustainability

cambridge.org/sus

Long Form Research Paper

Cite this article: Dornelles AZ *et al*. (2020). Towards a bridging concept for undesirable resilience in social-ecological systems. *Global Sustainability* **3**, e20, 1–12. https://doi.org/10.1017/sus.2020.15

Received: 13 June 2019
Revised: 9 June 2020
Accepted: 10 June 2020

Keywords:
lock-in; regime shifts; sustainable development; tipping points; transformations

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CAMBRIDGE UNIVERSITY PRESS

Towards a bridging concept for undesirable resilience in social-ecological systems

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Non-technical summary

Resilience is a cross-disciplinary concept that is relevant for understanding the sustainability of the social and environmental conditions in which we live. Most research normatively focuses on building or strengthening resilience, despite growing recognition of the importance of breaking the resilience of, and thus transforming, unsustainable social-ecological systems. Undesirable resilience (cf. *lock-ins*, *social-ecological traps*), however, is not only less explored in the academic literature, but its understanding is also more fragmented across different disciplines. This disparity can inhibit collaboration among researchers exploring interdependent challenges in sustainability sciences. In this article, we propose that the term *lock-in* may contribute to a common understanding of undesirable resilience across scientific fields.

Technical summary

Resilience is an extendable concept that bridges the social and life sciences. Studies increasingly interpret resilience normatively as a desirable property of social-ecological systems, despite growing awareness of resilient properties leading to social and ecological degradation, vulnerability or barriers that hinder sustainability transformations (i.e., 'undesirable' resilience). This is the first study to qualify, quantify and compare the conceptualization of 'desirable' and 'undesirable' resilience across academic disciplines. Our literature analysis found that various synonyms are used to denote undesirable resilience (e.g., path dependency, social-ecological traps, institutional inertia). Compared to resilience as a desirable property, research on undesirable resilience is substantially less frequent and scattered across distinct scientific fields. Amongst synonyms for undesirable resilience, the term *lock-in* is more frequently and evenly used across academic disciplines. We propose that *lock-in* therefore has the potential to reconcile diverse interpretations of the mechanisms that constrain system transformation – explicitly and coherently addressing characteristics of reversibility and plausibility – and thus enabling integrative understanding of social-ecological system dynamics.

Social media summary

'Lock-in' as a bridging concept for interdisciplinary understanding of barriers to desirable sustainability transitions.

1. Introduction

Resilience is a transdisciplinary concept used across the environmental, social, economic, political and health sciences. The concept refers to preventative and reactive capacities to resist or absorb a disturbance, to recover from stress or shocks, to reorganize through adaptation and to re-orientate through transformation in order to maintain essential functions (Chapin *et al.*, 2010; Folke *et al.*, 2010; Walker *et al.*, 2004). Resilience also cultivates the ability to persist and "sustain development in the face of change, incremental and abrupt, expected and surprising" (Folke, 2016, p. 7). The concept is useful to: (1) explore the dynamic transformational change of social-ecological systems (SESs) needed for Earth stewardship in the Anthropocene (Folke *et al.*, 2010; Reyers *et al.*, 2018); and (2) combine and complement various scientific paradigms into a working synthesis needed for sustainability science (Bettencourt & Kaur, 2011; Hediger, 1999).

As a descriptive concept, *resilience* incorporates insights from engineering, ecological, social-ecological, epistemic and intersubjective roots (Holling, 1973). How to define or measure *resilience* can vary widely across these perspectives (e.g., the notion of 'equilibrium' is considerably different between engineering and social-ecological narratives; Powell *et al.*, 2014; Weise *et al.*, 2020). As its use across academic disciplines has expanded and been refined for interdisciplinary collaboration over the years (Gao *et al.*, 2016; Tu *et al.*, 2019), so has its implicitly normative use (e.g., aims of 'building resilience'; Biggs *et al.*, 2015), especially in the translation of scientific work to policy and practice (Davoudi *et al.*, 2012) and/or to transdisciplinary applications where scientific knowledge is co-created with stakeholders from various sectors (Lang *et al.*, 2012). In other words, in parallel with its framing as a descriptive concept across disciplines (and beyond arguments of how to measure 'stable' or 'dynamic' properties), *resilience* has been continually reported as a desirable quality in a positive-normative fashion: ranging from resilient food systems (Schipanski *et al.*, 2016) and climate-resilient societies (James *et al.*, 2014) to resilient governmental institutions (Folke *et al.*, 2002). The use of the concept in this manner can create inconsistencies around the nature of analysing *resilience* (i.e., scientific concepts are not supposed to be inherently normative) and reveal inevitable debates around normative assumptions: every 'good' or 'desirable' quality has its 'bad' or 'undesirable' flipside.

While building and maintaining the *resilience* of SESs is often seen as a key activity to achieve sustainability (Biggs *et al.*, 2015), there is increasing recognition of resilient properties in some systems that 'lock-in' unfavourable regimes, thereby preventing transformation towards a more favourable state (Haider *et al.*, 2018; Phelan *et al.*, 2013; Standish *et al.*, 2014), or that 'lock-in' systems into unfavourable trajectories. We refer to this kind of resilience as 'undesirable resilience' on the basis that it leads to the persistence of undesirable outcomes (cf. Oliver *et al.*, 2018). The concept refers to resilient dynamics within intertwined properties, parts or levels of a system leading to undesirable outcomes in terms of sustainability for the environment and/or for society (Glaser *et al.*, 2018).

The use of *undesirable resilience* explicitly reveals its often implicit normativity and therefore the different goals and interests actors might have. *Resilience* that is desirable for one may be undesirable for others (Helfgott, 2018). Furthermore, elements of time and scale are also relevant for understanding the undesirability of resilience (Weise *et al.*, 2020): focusing on short-term benefits can undermine long-term desirable outcomes (Oliver *et al.*, 2018), and prioritizing only local or global scales can impair the assessment of cross-scale interconnectedness (Reyers *et al.*, 2018), even with an aim of overall benefits to wider society (e.g., the framing of the UN Sustainable Development Goals). Therefore, to ensure clear communication and to facilitate collaboration across disciplines, it is essential to critically analyse the concepts being referred to, distinguishing desirable and undesirable aspects of resilience and the normative assumptions ascribed to them in the resilience literature.

Scholars currently use a number of different terms to describe *undesirable resilience*, such as *path dependency* (Mahoney, 2000; Pierson, 2000), *institutional inertia* (Rosenschöld *et al.*, 2014), *maladaptation* (Barnett & O'Neill, 2010; Juhola *et al.*, 2016), *unhelpful resilience* (Standish *et al.*, 2014), *perverse resilience* (Phelan *et al.*, 2013) and more (Box 1). However, these terms appear to be tied to disciplinary narratives; their use and meaning have not been compared between disciplines, leading to potential miscommunication or inaccurate application in inter- or trans-disciplinary research. Here, we seek to quantify the extent to which the synonyms of *undesirable resilience* are used across multiple scientific fields in order to allow cooperation without explicit consensus (i.e., as a boundary object; Brand & Jax, 2007) or to actively link disciplines and stimulate dialogues between scientific and political realms (i.e., as a bridging concept; Davoudi *et al.*, 2012).

1.1. The value of bridging concepts in sustainability science

As a *boundary object* (*sensu* Brand & Jax, 2007) and a *bridging concept* (*sensu* Davoudi *et al.*, 2012), resilience has been used across many disciplines and has facilitated interdisciplinary approaches to diverse challenges in the Anthropocene, particularly in SESs (Baggio *et al.*, 2015). Several key benefits can be achieved when concepts travel across disciplines: (1) it prevents duplication of similar concepts under different names; (2) methods and approaches can be borrowed across disciplines, leading to more powerful analytical approaches to explore system dynamics (e.g., modelling approaches in social-ecological sciences; Lade *et al.*, 2017; Ngonghala *et al.*, 2017); and (3) interdisciplinary cross-talk allows for rich and malleable discussion of ideas, enabling the development of more plausible solutions to complex environmental, social and economic problems (Brand & Jax, 2007; Brown, 2015). Whilst some level of conceptual vagueness and ambiguity can be helpful for interdisciplinary interaction (Brand & Jax, 2007), a distinction must be made between a concept's *intention* (its meaning, its ontology) and its *extension* (the phenomena to which it applies) in order to prevent its uncritical use (problematic concept 'stretching'; Sartori, 1970). In this paper, we argue that the extension of resilience is stretched too far when it is used to account for both desirable and undesirable properties of SESs without appropriate clarification.

A central challenge for research is how to coherently grasp the differences and interrelations among sustainability, resilience and transformation (Folke *et al.*, 2010) through plausible and reconcilable approaches (Irwin *et al.*, 2018). Despite growing recognition of and evidence for self-reinforcing mechanisms and *vicious cycles* in SESs, many studies tend to pay attention predominantly to 'building' or 'enhancing' resilience and thereby neglect 'breaking' undesirable resilience (Barnosky *et al.*, 2012; Glaser *et al.*, 2018; Oliver *et al.*, 2018). Brown (2015, p. 36), for example, argues that despite resilience thinking carrying potential solutions for challenges of the contemporary age, "in many cases, resilience ideas are used to support and promote business as usual and

 https://doi.org/10.1017/sus.2020.15

Box 1. Definitions and use of synonyms of *undesirable resilience*.

Undesirable resilience: Resilience of aspects of a system that reinforce undesirable outcomes for society (Oliver *et al.*, 2018). For example, maintaining the economic resilience of global, modernized food supply chains often entails large-scale land acquisition by multinational private interests (to secure production across multiple territories to defray risks from extreme weather events, financial crashes or conflicts), but this can exacerbate and make more resilient undesirable outcomes for small farmers and local communities (e.g., biodiversity loss, food insecurity and power exclusion; EEA, 2015). Other proposed examples are resilient invasive species, antibiotic resistance, chronic poverty and concentration of power (IPES-Food, 2016).

Path dependency: According to Mahoney (2000, p. 507), path dependency refers to "historical sequences in which contingent events set into motion institutional patterns or event chains that have deterministic properties." A narrower perspective suggested by Pierson (2000, p. 252) sees it as a social process grounded in a dynamic of 'increasing returns', whereby "preceding steps in a particular direction induce further movement in the same direction." Increasing returns preserve and reinforce the structures and practices required to keep a system intact and functioning, thereby impairing local or regional transformation or innovation and enhancing power asymmetries (Hassink, 2005). Modern industrial agriculture, for example, requires specialized machinery, inputs and networks in order to see the return of these investments, to spread the costs of production and to achieve competitive prices (IPES-Food, 2016).

Institutional inertia: According to Rosenschöld *et al.* (2014, p. 639), institutional inertia can be understood as "the tendency of institutions within the political arena to resist change and thereby stabilize policy." Different mechanisms can generate and regenerate institutional inertia: costs, uncertainty, path dependency, power and legitimacy. Termeer *et al.* (2018), for example, demonstrated the extension of institutional inertia in South African fragmented government structures, which persisted in excluding the people most affected by food insecurity despite ambitious objectives of governance arrangements. Additionally, the 'stickiness' of institutions to move slowly or resist change can impair the international partnership needed for the Sustainable Development Goals (SDG number 17), especially the persistence of policy disconnects among countries (e.g., unsustainable agricultural subsidies and land-use reforms; IAP, 2018).

Lock-in: Lock-in occurs through a combined process of "technological and institutional co-evolution driven by path dependency increasing returns to scale" (Unruh, 2000, p. 817). Lock-in mechanisms can be characterized in terms of the plausibility of overcoming them and their reversibility (Supplementary Figure S5). We suggest an integrative definition of lock-in mechanisms: *dynamic interactions between social-ecological drivers and tipping points that are likely to lead to traps, maladaptation or to hindering transformational change towards sustainability*.

Perverse resilience: Perverse resilience refers to "resilience within a system that is undesirable to the extent that it is socially unjust, inconsistent with ecosystem health or threatens overall system viability" (Phelan *et al.*, 2013, p. 202). The concept unveils social norms and power relations in relation to the dynamic of social-ecological systems by linking concepts of resilience and hegemony. Perverse resilience of the coal industry interested in maintaining coal dependency in Australia, for example, has influenced labour unions and governments and led to ineffective policies and action responses designed to halt anthropogenic climate change (Evans, 2008).

Social trap: This term refers to the conjuncture of factors that enhance vulnerabilities. The term is broadly defined and as such applied across a number of social disciplines. Most research on social traps focus on poverty traps, defined as historical and cultural lacks of opportunities and capacities that reinforce a life below certain assets thresholds (Barrett & Swallow, 2006). Additionally, chronic poverty, path dependency and lock-ins are suggested to be types of traps across disciplines and share common characteristics: persistence, undesirability and self-reinforcement (Haider *et al.*, 2018).

Maladaptation: A term suggested by Barnet and O'Neill (2010 as "action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups" (p. 211). It has been further developed by Juhola et al. (2016), who wanted to use the concept to understand political outcomes: "a result of an intentional adaptation policy or measure directly increasing vulnerability for the targeted and/or external actor(s), and/or eroding preconditions for sustainable development by indirectly increasing society's vulnerability" (p. 135). Maladaptive outcomes can be summarized as three types: rebounding vulnerability, shifting vulnerability and eroding sustainable development.

Social-ecological trap: Social-ecological traps refer to complex interactions between social and environmental factors, such as environmental degradation, exposure to violence or poor sanitary conditions that reinforce vulnerabilities (Boonstra & de Boer, 2014). In comparison to social traps, this term integrates insights from development economics and sustainability sciences, incorporating four additional characteristics: cross-scale interactions, path dependencies, the role of external drivers and social-ecological diversity (Haider *et al.*, 2018). Trap dynamics, low connectedness and low resilience of a social-ecological system can all lead to social-ecological traps.

Unhelpful resilience: This term refers to the resilience of an ecosystem to a disturbance that impedes the return to a pre-disturbance state without assistance (Standish *et al.*, 2014). The term helps us to understand thresholds of disturbance in ecosystem management and to determine whether or not management interventions can be used to achieve a return to a pre-disturbance state. In contrast, helpful resilience indicates the capacity for unassisted return to a pre-disturbance state.

Wicked resilience: Wicked resilience was inspired by the distinct nature between 'wicked' and 'tame' problems, and thus Glaser *et al.* (2018) concluded that it is difficult if not impossible to objectively describe the term. Wicked resilience refers to interlocking 'wickedly' resilient vicious cycles predominantly driving the impoverishment, overexploitation, pollution and degradation of social-ecological systems. As such, a multi-level, multi-actor governance approach is required to overcome chronic, undesirable and wicked resilience from the local to the global level.

not to challenge the status quo." Resilience thinking and policy inevitably need to re-evaluate the existence of different academic and non-academic values, worldviews and framings of sustainability issues (Davoudi *et al.*, 2012; Miller *et al.*, 2014) in order to understand the non-linear, complex features and the uncertainty of change in SESs (Folke, 2016). Identifying the uncritical use of resilience as a potential issue can be used as an opportunity to initiate transformative change (Chapin *et al.*, 2010), particularly understanding and overcoming mechanisms of undesirable resilience.

In this paper, we explicitly distinguish *resilience* (increasingly used as a normatively desirable property) from *undesirable resilience*, which hinders systems' transformations towards sustainability. Through a citation analysis of the frequency and evenness in the use of various understandings and labels referring to undesirable resilience across disciplines, we assess the potential of these terms to serve as bridging concepts for sustainability science. We hypothesize that, in comparison to the single term *resilience*, different synonyms of undesirable resilience have been used in disciplinary silos – and are, therefore, less evenly referred to across disciplines, which limits their potential to serve as a bridging concept. This 'silo effect' can be particularly problematic in sustainability and SES research when: (1) different terms are used across disciplines to describe essentially equivalent or highly related concepts; and (2) isolated disciplinary inquiries artificially deconstruct intertwined aspects of SESs into a mere sum of the ecological or the social 'parts' (Reyers *et al.*, 2018). However, considering how the science system as it is today evolves, this 'silo effect' might also be a result of scientists being forced to enter and establish new fields, which sometimes are only separated from other fields through different key terms with similar meanings (Seppelt *et al.*, 2018). To investigate our hypothesis, we analysed the academic literature in two databases over the last five decades: Web of Science (WoS) and Scopus. Our aim was twofold: (1) to conduct a citation

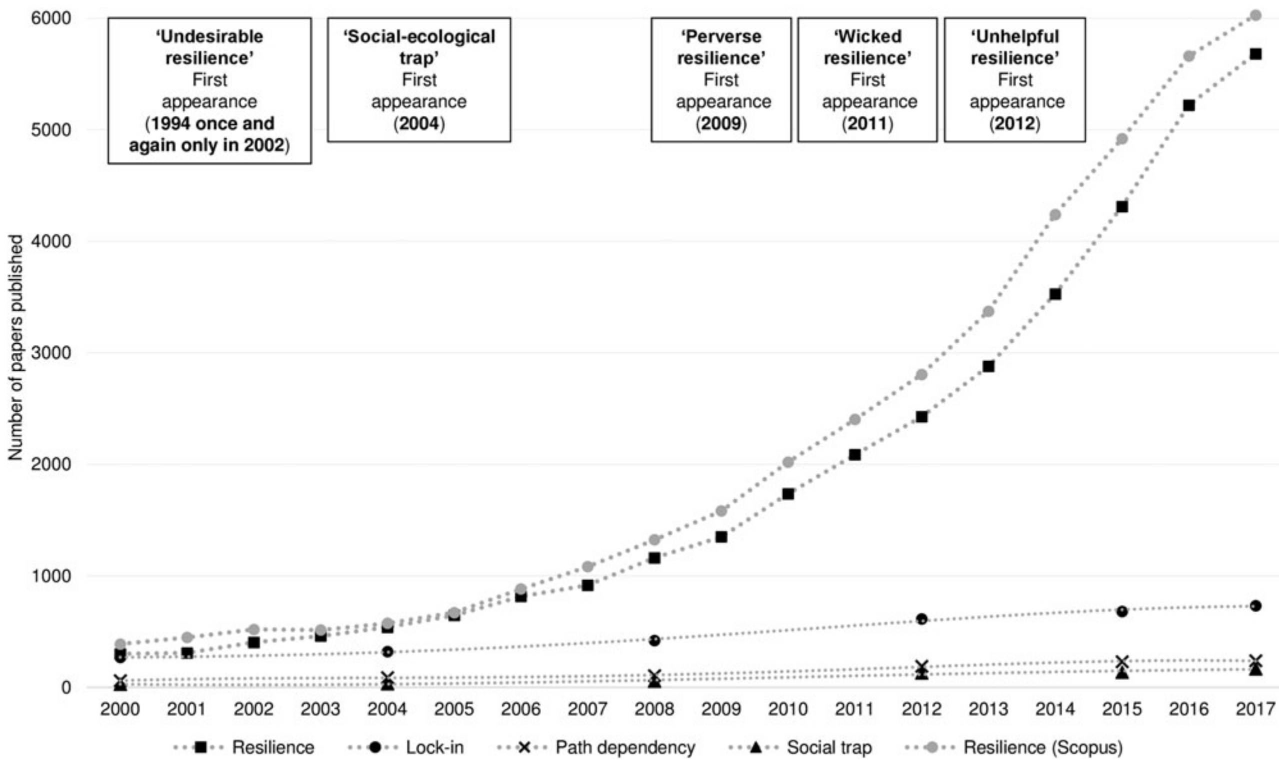

Fig. 1. Total number of papers published per year using the term *resilience* and synonyms of *undesirable resilience* in their title, abstract and/or keywords in Web of Science since 2000 (and using the term *resilience* in Scopus). For terms emerging after 2000, first appearances are shown at the top of the figure. Total sums of papers published (and compound annual growth rate[a] between 2000 and 2017) in Web of Science for the period were 41,479 (17.8%) for *resilience*, 9379 (5.7%) for *lock-in*, 2858 (8%) for *path dependency* and 1687 (10.6%) for *social trap*, whilst *resilience* in Scopus was 44,106 (16.5%). Trend lines for other terms are not shown due to total sum of papers below 1000 paper for the period, totalling 262 for *institutional inertia*, 977 for *maladaptation*, 132 for *undesirable resilience*, 39 for *social-ecological trap*, 11 for *unhelpful resilience*, 48 for *wicked resilience* and 9 *perverse resilience*.

[a] The compound annual growth rate is a measure of percentage increase per year and thus expresses the exponential growth of papers published using the term *resilience* in comparison to the other terms above over the same time period.

analysis of the standardized number of publications (i.e., frequency) and of the spread of papers published using synonyms of undesirable resilience across different scientific disciplines; and (2) to identify terms with potential to contribute to a common understanding and usage as a bridging concept for the comprehension of transformational change in SESs.

2. Methods

2.1. Literature analysis

We conducted a literature analysis of papers published using the term *resilience* and several synonyms of undesirable resilience in WoS and Scopus academic literature collections from 1970 to 2018. Synonyms of undesirable resilience were identified during an interdisciplinary expert workshop held in Leipzig in 2018 and included *undesirable resilience*, *institutional inertia*, *path dependency*, *lock-in*, *social traps*, *social-ecological traps*, *unhelpful resilience*, *maladaptation*, *perverse resilience* and *wicked resilience*. This set of terms comprises a non-exhaustive list based on the input of participants from a range of disciplines (Supplementary Table S1). The term *resilience* was used as a benchmark for comparison. To precisely assess the number of *resilience* papers published that did not include our targeted terms, the total search results for *resilience* were subtracted by the sum of papers that included terms for *perverse resilience*, *unhelpful resilience*, *undesirable resilience* and *wicked resilience*. Searches for publications were performed between June and August 2018, filtered by terms used in their title, abstract and/or keywords. Based on a pilot analysis, the timespan for the literature search was divided into two periods – 1970–1999 and 2000–2018 – because a considerable number of synonyms of undesirable resilience emerged after 2000 (Figure 1). With this division, we wanted to check for temporal differences and avoid anachronistic comparisons in the usage of different terms.

For each term and time period in our dataset, we used the same terminology and categorization of scientific fields employed by WoS and Scopus: the former uses 'broad research categories' and 'research areas', while the latter uses 'areas' and 'subject areas' (Supplementary Figure S1). To conduct our search through the WoS 'advanced research' tool, each term was specified in the 'topic' field (covering title, abstract and/or keywords fields within a record) and the respective scientific disciplines were identified by specific 'research area' (e.g., Sociology) – each classified within 'broad research categories'(e.g., Social Sciences). Search results were restricted to the document type 'articles', considering all languages, and to 'research areas' with more than 70,000 publications. To enable the selection of appropriate peer-reviewed published papers in the scientific fields and timeframes filtered, only 'Science Citation Index Expanded (SCI-EXPANDED)', 'Social Sciences Citation Index (SSCI)' and 'Arts & Humanities Citation Index (A&HCI)' were searched as citation indexes. In Scopus, the 'advanced search' tool was used to explore articles published across different scientific fields (defined as 'subject areas') that contained our selected terms of interest in the publication's title, abstract and/or keywords. Due to incompatible assignment of similar scientific fields between the two search engines, the data gathered were not merged and thus were analysed independently for WoS and Scopus.

2.2. Our integrative approach

We briefly describe the concept of *undesirable resilience* as social-ecological dynamics that reinforce vulnerabilities and/or hinder transformation towards sustainable development. 'Synonyms' used in this study are interpreted as different terms (i.e., linguistic and rhetoric elements) referring to identical or similar intentions or meanings of a concept (i.e., its ontology), but not necessarily to the same phenomena to which it applies (concept extension). This means that our argument for a 'bridging concept' does not intend to overwrite the nuances, specific processes or dimensions of terms described in their own literatures and contexts under a definitive unifying term. We rather aim to identify a term that can facilitate a common understanding of undesirable resilience and serve as a conceptual entry point for interdisciplinary communication. We find that there is potential for such a common understanding, because – although values, traditions and designs are inherently different across scientific disciplines – some features of the terms referring to *undesirable resilience* overlap (e.g., between *perverse* and *undesirable resilience*; between *social trap*, *path dependency* and *lock-in*).

2.3. Qualitative analysis: terms and academic disciplines

All terms analysed were discussed by the author team during the Leipzig workshop and their definitions were described based on key bibliography and how concepts currently are used in SES research primarily (Box 1). Relevant academic disciplines in WoS and Scopus were selected based on their similarities and relevance to the study of the terms identified. To balance the comparison of observations in our main analysis using all terms identified, the total number of disciplines selected was held equal for the two datasets (n = 9). In WoS, three broad research categories were explored: Arts & Humanities (AH), which included the research areas History and Philosophy (n = 2); Social Sciences (SS), including Business & Economics, Government & Law, Psychology and Sociology (n = 4); and Life Sciences & Biomedicine (LS), containing Agriculture, Behavioral Sciences and Environmental Sciences & Ecology (n = 3). In Scopus, four research categories were explored: Health Sciences (HS), including the subject area Medicine (n = 1); Life Sciences (LS), which contained Agricultural and Biological Sciences (n = 1); Physical Sciences (PS), consisting of Earth and Planetary Sciences and Environmental Science (n = 2); and Social Sciences (SS), composed of the following subject areas: Arts and Humanities; Business, Management and Accounting; Economics Econometrics and Finance; Psychology; and Social Sciences (n = 5).

A secondary analysis of 20 research areas specifically for the broad research categories of SS (n = 10) and for LS (n = 10) was conducted separately to further investigate the use of terms *resilience*, *lock-in* and *undesirable resilience* in WoS. The SS research areas included Area Studies, Business & Economics, Development Studies, Geography, Government & Law, International Relations, Psychology, Social Issues, Sociology and Urban Studies. Life Sciences & Biomedicine contained Agriculture, Anthropology, Behavioral Sciences, Biodiversity & Conservation, Developmental Biology, Environmental Sciences & Ecology, Evolutionary Biology, Marine & Freshwater Biology, Zoology and Public, Environmental & Occupational Health. A literature search for this secondary analysis was performed in February 2019, filtering publications by terms used in their title, abstract and/or keywords. Due to different categorizations, distinct assignments of academic disciplines and a more representative use of the term *undesirable resilience* in WoS from 2000 to 2018, this secondary analysis was not conducted in Scopus.

2.4. Quantitative analysis: frequency of use

Despite covering a substantial amount of the academic literature, no database is complete and balanced (Chadegani *et al.*, 2013). Both databases contain biases that favour the frequency of natural, biomedical and engineering sciences over AH and SS (Mongeon & Paul-Hus, 2016). To control for this potential limitation and increase the reliability of our analysis (i.e., comparing the number of papers published using the terms searched across different research areas), the number of articles published was standardized by the total number of papers published in each research area as follows: the standardized number of publications reflects the number of papers published using target terms (n) per total number of papers published in the research area (N) multiplied by one million (standard factor; i.e., expressed by papers per million papers):

$$n/N \times 10^6$$

2.5. Quantitative analysis: evenness of use

To test our hypothesis that synonyms for undesirable resilience are used within siloed, disconnected disciplinary approaches, we calculated the evenness in the use of terms in published papers across research areas (WoS) and subject areas (Scopus). For each term, the coefficient of variation (CV; described below) of the standardized number of publications (papers per million papers) was measured across academic disciplines.

CV expresses evenness of use by a simple calculation of standard deviation (σ) over the mean (μ). It reveals the degree of dispersion around the mean and thus is a useful measurement to compare variance even if the standardized number of publications shows highly different means for each of the terms assessed. This method has been used in ecology to assess the degree to which species abundance is spread evenly across discrete habitat types (Julliard *et al.*, 2006). In an analogous way, we use this metric to assess how the numbers of journal papers using a specific term are spread across different disciplines. We rank disciplines from the lowest to the highest CV value (i.e., from more to less even use of terms across disciplines; Julliard *et al.*, 2006), indicating terms that are more to less commonly shared across disciplines.

Additionally, Shannon–Wiener's (D^{SW}), Simpson's (D^{S}) and Berger–Parker's (D^{PB}) ecological indices (Baumgärtner, 2006) were applied to analyse the equivalent richness, abundance and equitability (evenness) for each target term used across research areas. In our study, terms searched correspond to 'species' and research areas represent 'communities'. The standardized numbers of publications were then ranked according to more to less even use of terms across disciplines (high to low values for D^{PB} and low to high values for all other metrics). The equations used are described below.

Richness (D^{R}) is the simplest measure of biodiversity of an ecosystem Ω and equates to the total number of different species found in that system (n). In our case, 'species' was equivalent to 'terms' and n represented how many times each term was found across the nine different research areas. This is often referred to as species richness:

$$D^R(\Omega) = n$$

Shannon–Wiener entropy summarizes the entropy of a community. It expresses the average amount of 'information' in the community by comparing rare species 'information' to common species and their information value (proportional to the logarithm of their proportional abundance in the community, p_i). In our study, terms are equivalent to species and research areas are the communities.

$$H = -\sum_{i=1}^{n} p_i \ ln \ p_i$$

Shannon–Wiener equitability (D^{SW}) is calculated by dividing the Shannon diversity index (entropy) by its maximum ($H_{\max}$). Therefore, it varies between 0 and 1 (or 0% and 100%), with higher values indicating greater community evenness.

$$D^{SW} = H/H_{\max}$$

Simpson's index (D^S) refers to the probability that two randomly selected specimens from a sample will be of two different species. In theory, this metric ranges from 0 (perfectly uneven) to 1 (perfectly even). It expresses a true probability value.

$$D^S = 1 \ / \sum_{i=1}^{n} p_i^2$$

Berger–Parker's index (D^{PB}) equals the maximum p_i value in the dataset (i.e., the proportional abundance of the most abundant type). If Berger–Parker's index is high, this means that the community is dominated by the most common species (i.e., it is not even).

3. Results

The results presented here are primarily from our search in the WoS focusing on literature published between 2000 and 2018 due to the more representative use of synonyms of undesirable resilience in this database. The results for Scopus broadly support the WoS results (Supplementary Results, Supplementary Figure S2 & Supplementary Table S2), although the former reports them in 'areas' and 'subject areas', whilst the latter uses 'broad research categories' and 'research areas' for assignment.

Research using the term *resilience* has increased steadily over recent years (Figure 1). In WoS, in the research areas explored in our literature analysis, it has increased from 830 total papers using the term in their title, abstract and/or keywords between 1970 and 1999 to 17,505 papers between 2000 and 2018 (Table 1). *Resilience*, which may be used to denote both normative desirable and undesirable proprieties, is much more commonly used than *undesirable resilience* and its synonyms that explicitly account for undesirability (Supplementary Figure S3), exceeding their combined use (4256 papers) by more than four times from 2000 to 2018. In this period, *lock-in*, *path dependency* and *social trap* are the most frequently used synonyms, with 1697, 1069 and 845 publications, respectively. From 1970 to 1999, combined use of synonyms of undesirable resilience (490 papers) represented approximately half of the publications that mention *resilience*, whilst *undesirable resilience* had a single appearance in 1994. Other synonyms of undesirable resilience emerged later: *social-ecological trap* first appeared in 2004, *perverse resilience* in 2009, *wicked resilience* in 2011 and *unhelpful resilience* was used for the first time as late as 2012 (Figure 1).

Synonyms of undesirable resilience are used substantially less frequently than *resilience* by standardized number of papers (i.e., controlling for differences in the total number of papers published in research areas). This is true across all nine specific WoS research areas from 2000 to 2018 (Figure 2). Across three broad research categories (AH, SS and LS) from 2000 to 2018 in WoS, *resilience* is also the most frequent of our search terms. *Resilience* is at least four times more frequently used than all terms related to undesirable resilience in the AH literature, and at least seven and 13 times more frequent in the SS and LS literatures, respectively (Supplementary Table S3).

Among the three broad research categories, AH has the lowest use of synonyms of undesirable resilience (i.e., lowest percentage of publications using target terms) besides *perverse resilience*, *wicked resilience* and *institutional inertia* (Figure 3). The terms *lock-in*, *path dependency* and *institutional inertia* are more prevalent in SS, whilst *wicked resilience*, *social trap*, *unhelpful resilience*, *maladaptation*, *undesirable resilience* and *social-ecological trap* are most predominantly used in Life Sciences & Biomedicine. Terms with the most even usage across all three broad research categories are *perverse resilience*, *lock-in* and *path dependency* (CV values of 0.43, 0.61 and 0.62, respectively), whilst *resilience* was ranked fourth (CV = 0.67) due to its low relative frequency of use in AH.

Across the nine more specific WoS research areas, all synonyms of undesirable resilience are used more unevenly compared with *resilience* (lowest CV value of 0.76, reflecting the most even distribution across research areas; Figure 2). The synonyms of undesirable resilience that are most evenly used across research areas are *social trap* (CV = 0.85), *path dependency* (CV = 0.95) and *lock-in* (CV = 1.03). The D^{SW} and D^S ecological indices identified an identical ranking for evenness of use across research areas: *resilience* is the term most evenly used ($D^{SW} = 0.89$; $D^S = 0.83$; higher values indicating more even use for these metrics), followed by *social trap* ($D^{SW} = 0.87$; $D^S = 0.82$), *path dependency* ($D^{SW} = 0.82$; $D^S = 0.80$) and *lock-in* ($D^{SW} = 0.83$; $D^S = 0.79$; Supplementary Table S4). Similar patterns are found in Scopus for the evenness of terms used across subject areas (Supplementary Figure S2).

Amongst the synonyms of undesirable resilience, *lock-in* is the most widely used term in both absolute and standardized numbers of publications, with 1697 publications using the term and 4701 publications per million papers across all research areas. It is also used commonly across different academic disciplines: it is ranked second and third by evenness of use (i.e., with regard to the CV value) across broad research categories and specific research areas, respectively (Figures 2 & 3). Other synonyms that are also used across multiple research areas are *path dependency*, *social trap* and *perverse resilience*, but are all less frequently used than *lock-in* (1069, 849 and 8 absolute publications, respectively). In a wider comparison of 20 research areas from two broad research categories (SS and LS), evenness of *lock-in* use (CV = 0.58 in SS and 0.85 in LS) is similar to the use of *resilience* (CV = 0.53 in SS and 0.77 in LS), while *undesirable resilience* is substantially less evenly used (CV = 1.38 in both SS and LS) across research areas (Supplementary Figure S4 & Supplementary Table S5).

Table 1. Total number of papers published using the terms *resilience* and synonyms of *undesirable resilience* in their title, abstract and/or keywords assigned across nine specific Web of Science research areas between 1970 and 2018.

	Total papers published		Terms									
			Resilience		*Undesirable resilience*		*Path dependency*		*Lock-in*		*Social trap*	
Research Area	1970–1999	2000–2018	1970–1999	2000–2018	1970–1999	2000–2018	1970–1999	2000–2018	1970–1999	2000–2018	1970–1999	2000–2018
History (AH)	128,911	129,744	14	175	0	0	2	34	4	39	3	24
Philosophy (AH)	81,223	103,325	7	91	0	0	0	15	3	28	4	16
Business & Economics (SS)	312,317	464,957	53	1,595	0	8	34	401	91	816	25	179
Government & Law (SS)	209,184	159,709	29	479	0	0	8	170	15	160	9	73
Psychology (SS)	429,978	518,496	301	4,850	1	5	17	70	17	90	33	70
Sociology (SS)	70,572	76,096	27	557	0	2	12	71	2	22	12	83
Agriculture (LS)	384,839	456,349	78	1,086	0	5	1	31	8	50	1	29
Behavioral Sciences (LS)	69,759	87,219	7	293	0	0	0	4	5	19	6	72
Environmental Sciences & Ecology (LS)	341,076	811,241	314	8,379	0	53	5	273	19	473	57	303

	Terms											
	Institutional inertia		*Maladaptation*		*Social-ecological trap*		*Unhelpful resilience*		*Wicked resilience*		*Perverse resilience*	
	1970–1999	2000–2018	1970–1999	2000–2018	1970–1999	2000–2018	1970–1999	2000–2018	1970–1999	2000–2018	1970–1999	2000–2018
History (AH)	0	7	2	3	0	0	0	0	0	1	0	1
Philosophy (AH)	0	2	2	4	0	0	0	0	0	1	0	0
Business & Economics (SS)	14	85	1	7	0	1	0	1	0	3	0	1
Government & Law (SS)	6	42	1	2	0	0	0	0	0	1	0	1
Psychology (SS)	0	3	42	89	0	0	0	1	0	1	0	0
Sociology (SS)	3	16	4	4	0	0	0	0	0	0	0	0
Agriculture (LS)	0	1	1	5	0	1	0	1	0	1	0	0
Behavioral Sciences (LS)	0	0	6	15	0	0	0	0	0	0	0	0
Environmental Sciences & Ecology (LS)	4	40	10	176	0	17	0	3	0	26	0	5

AH = Arts & Humanities; LS = Life Sciences & Biomedicine; SS = Social Sciences.

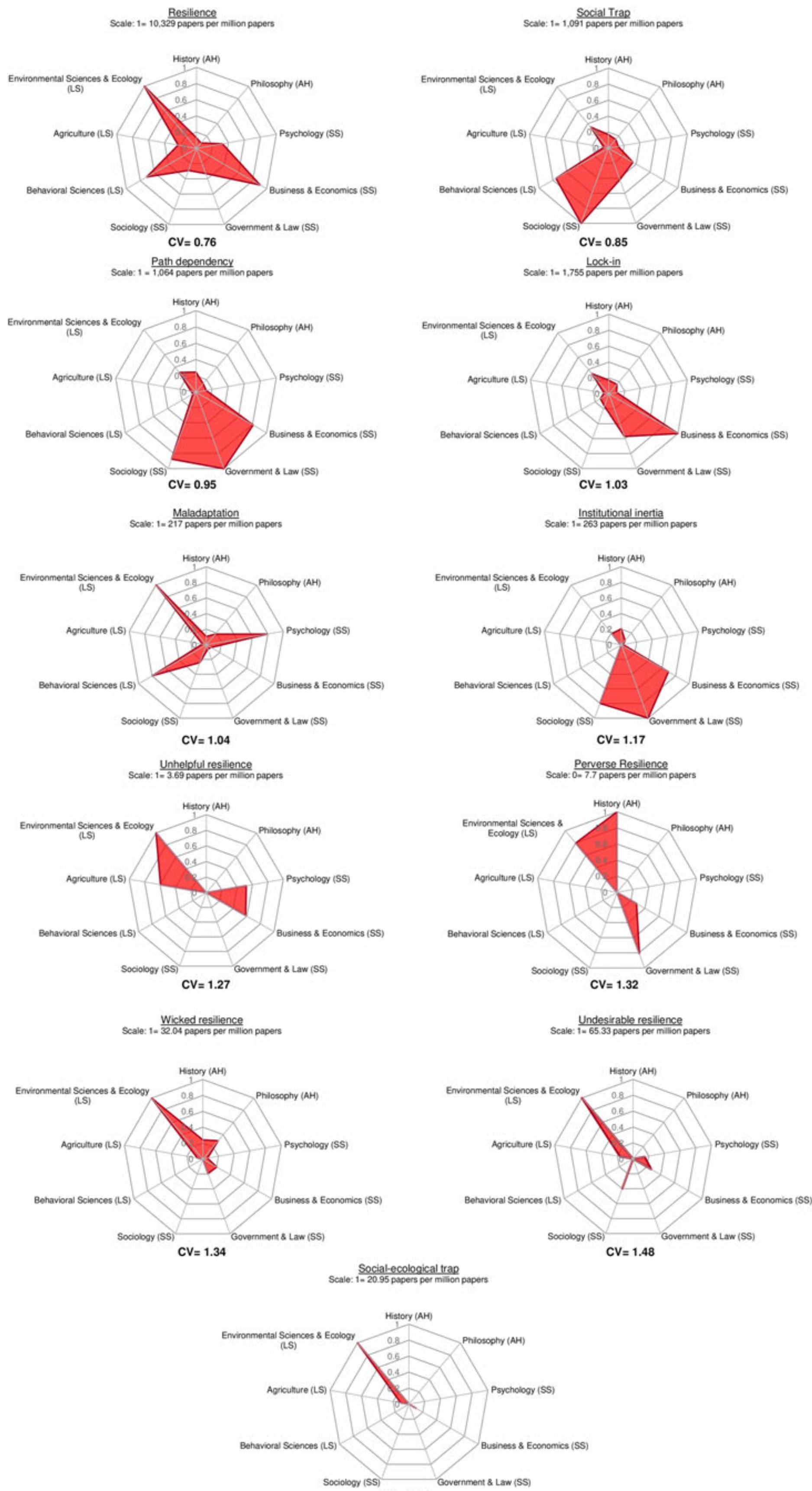

Fig. 2. Standardized numbers of papers published using the term *resilience* and synonyms of *undesirable resilience* in their title, abstract and/or keywords assigned across nine specific Web of Science research areas from 2000 to 2018. Numbers of papers per million papers are plotted through a proportional scale ranging from 0 to 1, the latter representing the maximum value of the standardized number of publications for each term across research areas. Radar graphs are ordered by coefficient of variation (CV) value, reflecting increasingly uneven use across the different research areas. AH = Arts & Humanities; LS = Life Sciences & Biomedicine; SS = Social Sciences.

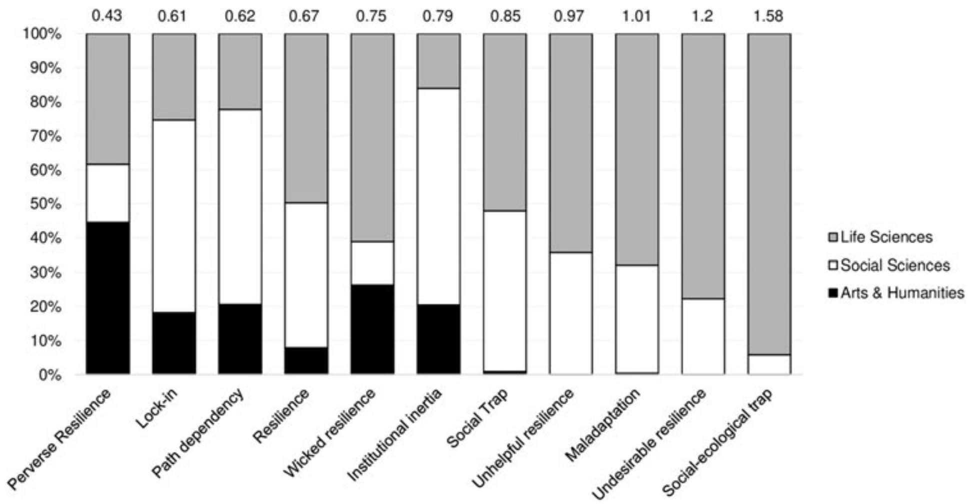

Fig. 3. Relative standardized numbers of papers published using the term *resilience* and synonyms of *undesirable resilience* in their title, abstract and/or keywords assigned across three broad Web of Science research categories from 2000 to 2018. Bars are ordered by coefficient of variation value, which are detailed at the top of the figure. Lower values reflect more even use across the three broad research categories.

4. Discussion

We found that papers using *undesirable resilience* and its synonyms are substantially less frequent than those using the term *resilience*. Simultaneously, publications using synonyms of undesirable resilience are usually restricted to specific scientific fields, shown by a lower spread of papers published across disciplines – supporting our hypothesis of a 'silo effect' that artificially and arbitrarily reduces intertwined parts of SESs to explain them through isolated disciplinary inquires (Reyers *et al.*, 2018). Amongst synonyms of *undesirable resilience*, *lock-in*, *path dependency* and *social trap* are used more frequently and evenly across the disciplines explored. The combination of our quantitative and qualitative analysis suggests that *lock-in* appears to hold most potential as an informative interdisciplinary bridging concept.

Amongst the synonyms of *undesirable resilience* we investigated, the term *lock-in* ranked first for total and standardized numbers of publications and second for evenness of use across broad research categories (third across specific research areas). Furthermore, based on a qualitative analysis of current definitions in the academic literature (Box 1), we argue that *lock-in* best reflects the positive (reinforcing) and negative (stabilizing) feedback processes that prevent system transition from an undesirable equilibrium or trajectory. Other synonyms, such as *path dependency* or *institutional inertia*, denote tendencies that conserve the status quo (by referring to historical deterministic properties or exclusively to the role of institutions, respectively), but do not necessarily capture the complexity of feedback dynamics inherent in resilient SESs (Peters *et al.*, 2005). The resilience of SESs, be it desirable or undesirable, is influenced by a wide range of intertwined mechanisms and processes that lock-in the functioning and development of social-ecological interactions, which need to be examined holistically (e.g., cross-scale dynamics and systemic tipping points; Reyers *et al.*, 2018). Therefore, *lock-in* broadens the scope of study beyond reductionist conclusions that describe states or trajectories of change restrictively. As the most frequently used of the *undesirable resilience* synonyms and as an integrative bridging concept, we find that *lock-in*, as a term to designate *undesirable resilience*, has most potential to harness insights from LS and SS to contribute to a deeper understanding and purposeful management of sustainability transitions.

Further support for using *lock-in* as a bridging concept can be gained from its interrelation with the evolution of the concept *tipping point* – commonly used to refer to a rapid, potentially irreversible transition of a SES. Milkoreit *et al.* (2018) conducted an extensive review of similar terms that were used to describe this type of transition (e.g., *regime shifts*, *critical transitions*) and found that integration was particularly difficult due to at least 23 distinct disciplinary features for its definition – equivalent to the problem of concept stretching (cf. Sartori, 1970) for *resilience* or to challenges of overlapping features shared across synonyms of *undesirable resilience*. The authors proposed a general definition for use of *tipping point* as a bridging concept: "[T]he point or threshold at which small quantitative changes in the system trigger a non-linear change process that is driven by system-internal feedback mechanisms and inevitably leads to a qualitatively different state of the system, which is often irreversible" (Milkoreit *et al.*, 2018, p. 9). *Tipping point* is mostly used with reference to transitions away from desirable system states (i.e., a lack of *resilience* allows triggering of a *tipping point* into an undesirable state). However, a tipping process necessarily involves breaking resilience and can equally be surpassed to transition from an undesirable to a more desirable state or pathway. Hence, in relation to our focus on *undesirable resilience* here, overcoming *locked-in* situations (i.e., breaking *undesirable resilience*) can enable rapid system transformation towards more positive outcomes. In this sense, addressing underlying dynamics (*lock-in* mechanisms) that prevent *tipping points* towards achieving more desirable states is necessary to understand system transformations (TWI2050, 2018), but unveils conceptual challenges of its own.

4.1. Lock-in mechanisms: three challenges for an integrative concept for undesirable resilience

We identify three challenges for the use of *lock-in* as an integrative concept for *undesirable resilience*: (1) reconciling the mechanisms of desirable *resilience* from undesirable *lock-in*; (2) its inherent normativity; and (3) its extension across disciplinary boundaries. A first challenge for the interdisciplinary use of *lock-in* is the reconciliation between aspects of desirable *resilience* and undesirable *lock-ins* across a hierarchy of timescales, spatial scales and different actors. Although we argue that the term *lock-in* is a useful point of interdisciplinary convergence, we need to carefully consider its application as an extendable concept. To distinguish desirable from undesirable *resilience* requires reflexivity to deconstruct the various mechanisms that sustain or *lock-in* undesirable SES states or trajectories. For example, Oliver *et al.* (2018) identified over 20 different mechanisms that prevent the transformation of food systems towards configurations that are less environmentally and socially damaging (they grouped *lock-in* mechanisms into four categories: knowledge based, economic/regulatory, sociocultural and biophysical). Similar approaches could be taken to deconstruct *lock-ins* that constrain the reversal of anthropogenic pressures in different Earth systems (Seppelt *et al.*, 2014; Steffen *et al.*, 2015), as well as identifying interdependent constraints in achieving goals of well-being and development (Raworth, 2017).

We considered two important characteristics of the first challenge for an integrative definition of *lock-in* that can address *undesirable resilience* in different contexts: reversibility and plausibility. In some contexts, even though *lock-ins* are technically reversible (i.e., 'hysteresis' can be overcome; Milkoreit *et al.*, 2018), they may still be implausible to overcome due to dynamic interactions pushing the system towards undesirable outcomes (e.g., coexistence of *social-ecological traps* and *institutional inertia* that synergistically reinforces vulnerabilities). On the other hand, it might be plausible to prevent reaching an undesirable irreversible tipping point if reasonable conditions support an agreement among stakeholders to implement innovative interventions towards more desirable or just forms of sustainability. In other words, it is essential to understand the plausibility of addressing *lock-in* mechanisms in order to prevent reaching irreversible tipping points or strong hysteresis. For a more comprehensive understanding of the dynamic mechanisms behind undesirable states or trajectories leading to undesirable tipping points, we argue that three potential intersections between the reversibility and plausibility of overcoming problems can be summarized as: 'hard' *lock-in* mechanisms (i.e., a combination of strong social-ecological drivers and strong hysteresis or irreversible tipping points); 'soft' *lock-in* mechanisms (i.e., weaker social-ecological drivers and weak hysteresis); and tame problems (apparent absence of *lock-in* mechanisms: reversible and plausibly resolvable problems; Supplementary Figure S5).

The second challenge for an integrative concept concerns the inherent normativity, such as in the term *lock-in*, that addresses *undesirable resilience*. Defining what is (un)desirable *resilience* inevitably implies normative and moral judgements and thus raises questions on equity, agency, distribution of power and politics (Boonstra, 2016; Davoudi *et al.*, 2012). It means that if the undesirability of *resilience* is not explicitly debated, taking into account values, interests and power (shaping both conduct and context; Boonstra, 2016), the concept runs the risk of inappropriately informing management and policy. For example, it might result in "societal adaptation and resilience to sustained unsustainability" (Blühdorn, 2016, p. 10) or it might be used to justify initiatives favouring incremental adaptation only (Reyers *et al.*, 2018). Once the normative assumptions around resilience 'of what', 'to what', 'for whom' and 'at what timescale' are made explicit, this enables a more reasonable distinction of how and why change towards sustainability can be implemented (Helfgott, 2018; Weise *et al.*, 2020). Scholars working on the interrelated paradigm of sustainability have argued that the politics of *unsustainability* (Blühdorn, 2016, p. 9) turned "sustaining the unsustainable into an imperative," rather than aiming to deliver structural changes to prevent undesirable social conflicts and ecological collapse. Clearly, it is important to avoid the potential of conceptual stretching in the uncritical use of *lock-in*.

The third and final challenge to consider relates to the extension of the term *lock-in* to address the concept of *undesirable resilience* across disciplinary boundaries. A coherent interdisciplinary approach to *lock-in* mechanisms using terminology consistently across disciplines requires academic humility and reflexivity to recognize that different cultural values and perspectives underpin scientific disciplines (Rockström *et al.*, 2018) and to acknowledge distinct working traditions. Notwithstanding the value of this diversity, interdisciplinary integration is highly worthwhile in sustainability science, where concepts and methods need to be integrated to enable communication and synergies in order to progress sustainability thinking within as well as beyond academia (i.e., transdisciplinary research; Lang *et al.*, 2012).

Overcoming these challenges is warranted not only to establish *lock-in* in order to differentiate undesirable from desirable *resilience*, but also to enable a richer analysis of the mechanisms leading to undesirable states or trajectories. The explicit attention to *undesirable resilience* and mechanisms of *lock-in* can help us to better understand social-ecological dynamics and, consequently, contribute to designing appropriate interventions. For example, in a poverty trap study using multidimensional models, Lade *et al.* (2017) concluded that it is impossible to understand persistent poverty without explicitly accounting for multiple positive (reinforcing) and negative (stabilizing) feedback interactions that, in respect to our study, might lead to persistent undesirable consequences in SESs (i.e., *locked-in* systems). Transcending one-dimensional perspectives requires new theoretical advances to explore the interplay between mechanisms that underpin traps, potential alleviation strategies and wider social-ecological factors. Similarly, Ngonghala *et al.* (2017) found that negative feedbacks between ecological, economic and epidemiological parameters are of primary importance for developing integrated interventions to tackle persistent poverty.

Lock-in mechanisms and complex feedbacks are also important for exploring the potential interaction between simultaneous trajectories and goals. In processes of agricultural transition and urbanization, mutual reinforcement of technological change, population growth and patterns of urbanization can potentially lead to social-ecological traps and ecosystem overexploitation (Cumming *et al.*, 2014). Finally, acknowledging *lock-in* mechanisms can help us to interpret obstacles and guide planning in holistic and multidimensional models of interactions (synergies and trade-offs) amongst, for instance, the United Nations Sustainable Development Goals (Pradhan *et al.*, 2017). Hence, identifying and quantifying the self-reinforcing and often non-linear features that *lock-in* SESs to undesirable states or trajectories is a crucial focus for progressing sustainability science and transitions.

Bearing in mind these three challenges, we identify an opportunity for the term *lock-in* to contribute as an integrative concept for understanding *undesirable resilience* in sustainability science. As an extendable concept, its coherent use must carefully consider underlying values and conceptual complexity from different scientific perspectives and appropriately incorporate plurality of understanding among disciplines. A common understanding and the usage of *lock-in*, in this sense, have the potential to simultaneously: (1) describe the mechanisms that reinforce vulnerabilities and/or hinder transformation towards sustainability across disciplines; (2) raise awareness of highly relevant aspects of *undesirable resilience* that are often overlooked; (3) facilitate conceptual progress while maintaining rich and diverse discussions; and (4) improve the consistency of discourse and research as a complementary concept to *resilience* in sustainability science.

4.2. Reflections on the literature analysis

To our knowledge, this is the first study to quantitatively assess the frequency and evenness of use of synonyms of *undesirable resilience* and to qualitatively identify and compare them across different disciplines in the academic literature. To this purpose, we explored two academic literature collections: WoS and Scopus. They both cover the majority of published scientific material, but some limitations must be considered. A key constraint is the incompatibility between the two datasets that stems from the use of different terminology and criteria for the assignment of papers across scientific disciplines. Differences in how, for example, 'research areas' (WoS) and 'subject areas' (Scopus) categorize publications complicate comparison. Although WoS and Scopus might use similar names for research and subject areas, these include different subcategories and are also aggregated differently into 'broad research categories' (WoS) or 'areas' (Scopus). This inconsistency in assignment and categorization becomes very clear for multidisciplinary research: 'Multidisciplinary Sciences' is categorized as a specific subject category in WoS, whilst 'Multidisciplinary' is assigned under HS in Scopus. Thus, we could not directly compare results between WoS and Scopus, but only through standardized numbers of papers and different indices of evenness of use across disciplines within each academic repository separately. In summary, by considering the two databases, our search has been considerably exhaustive.

5. Conclusion

As a bridging concept, *resilience* has been useful in developing interdisciplinary collaboration and synergy for sustainability science. Yet, with the growing use of the term across disciplines, important distinctions are lost, which limits its ability to inform sustainability transformations that often require overcoming negative-feedback mechanisms that trap systems in undesirable states or trajectories. In this paper, we suggest drawing a distinction between *resilience* and its overlooked flipside *undesirable resilience*. Here, we found that research on synonyms related to *undesirable resilience* is not only substantially less frequent in comparison to *resilience*, but also tends to artificially deconstruct intertwined parts of SESs to explain them through specific scientific fields with their own distinct terms. Of these synonyms, the term *lock-in* is the most frequently and commonly used across several scientific disciplines. To address the lack of a common understanding of *undesirable resilience*, we argue that *lock-in* offers opportunity as a bridging concept that allows quantitative and qualitative analysis of constraint mechanisms – explicitly and coherently addressing characteristics of reversibility and plausibility. Common understanding and usage of *lock-in* can integrate insights and methodologies across disciplines contributing to sustainability science and can improve the consistency of *resilience* thinking as a complementary concept, and thereby enable a more comprehensive exploration of social-ecological dynamics towards more sustainable futures. Finally, work remains to be done to reconcile the normative assumptions and moral implications of the (un)desirable aspects of *resilience* across a hierarchy of timescales, spatial scales and different actors.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/sus.2020.15

Acknowledgements. This paper is a joint effort of the working group 'sOcioLock-in' and an outcome of a workshop kindly supported by sDiv, the Synthesis Centre of the German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig (DFG FZT 118). We thank all organizers, participants and administrative staff involved in the sDiv working group sOcioLock-in. We also thank the editor-in-chief and the two anonymous reviewers from *Global Sustainability* for the valuable and constructive comments that improved the quality of our work.

Author contribution. All co-authors contributed to article planning and writing. André Dornelles was responsible for collating the data, whilst the analysis was conducted by André Dornelles, Tom Oliver, Matthias Schröter and Ralf Seppelt.

Financial support. The 'sOcioLock-in' workshop was funded by sDiv, and this study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brazil (CAPES) – Finance Code 001. André Dornelles is funded by a Brazilian CAPES scholarship.

Conflict of interest. None.

Publishing ethics. This research and article comply with *Global Sustainability*'s publishing ethics guidelines.

Data availability. The authors declare that the data supporting the findings of this study are available within the paper and its Supplementary Material. All of the data were extracted from the Web of Science (https://clarivate.com/products/web-of-science) and Scopus (https://www.scopus.com) academic collections, and the exact search string is described above.

References

Baggio, J. A., Brown, K. & Hellebrandt, D. (2015). Boundary object or bridging concept? A citation network analysis of resilience. *Ecology and Society*, *20*(2), 2.

Barnett, J. & O'Neill, S. (2010). Maladaptation. *Global Environmental Change*, *20*(2), 211–213.

Barnosky, A. D., Hadly, E. A., Bascompte, J., Berlow, E. L., Brown, J. H., Fortelius, M., … Smith, A. B. (2012). Approaching a state shift in Earth's biosphere. *Nature*, *486*(7401), 52–58.

Barrett, C. B. & Swallow, B. M. (2006). Fractal poverty traps. *World Development*, *34*(1), 1–15.

Baumgärtner, S. (2006). Measuring the diversity of what? And for what purpose? A conceptual comparison of ecological and economic biodiversity indices. *SSRN Electronic Journal*. Retrieved from https://doi.org/10.2139/ssrn.894782

Bettencourt, L. M. A. & Kaur, J. (2011). Evolution and structure of sustainability science. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(49), 19540–19545.

Biggs, R., Schlüter, M. & Schoon, M. L. (eds) (2015). *Principles for Building Resilience: Sustaining Ecosystem Services in Social-Ecological Systems*. Cambridge University Press.

Blühdorn, I. (2016). *Sustainability – Post-Sustainability – Unsustainability*. T. Gabrielson, C. Hall, J. M.

Boonstra, W. J. (2016). Conceptualizing power to study social-ecological interactions. *Ecology and Society*, *21*(1), 21.

Boonstra, W. J. & de Boer, F. W. (2014). The historical dynamics of social-ecological traps. *AMBIO*, *43*(3), 260–274.

Brand, F. & Jax, K. (2007). Focusing the meaning(s) of resilience: resilience as a descriptive concept and a boundary object. *Ecology and Society*, *12*(1). 23.

Brown, K. (2015). *Resilience, Development and Global Change*. Routledge.

Chadegani, A. A., Salehi, H., Yunus, M. M., Farhadi, H., Fooladi, M., Farhadi, M. & Ebrahim, N. A. (2013). A comparison between two main academic literature collections: Web of Science and Scopus databases. *Asian Social Science*, *9*(5), 18–26.

Chapin, F. S., Carpenter, S. R., Kofinas, G. P., Folke, C., Abel, N., Clark, W. C., … Swanson, F. J. (2010). Ecosystem stewardship: sustainability strategies for a rapidly changing planet. *Trends in Ecology & Evolution*, *25*(4), 241–249.

Cumming, G. S., Buerkert, A., Hoffmann, E. M., Schlecht, E., von Cramon-Taubadel, S. & Tscharntke, T. (2014). Implications of agricultural transitions and urbanization for ecosystem services. *Nature*, *515*(7525), 50–57.

Davoudi, S., Shaw, K., Haider, L. J., Quinlan, A. E., Peterson, G. D., Wilkinson, C., … Davoudi, S. (2012). Resilience: a bridging concept or a dead end? 'Reframing' resilience: challenges for planning theory and practice interacting traps: resilience assessment of a pasture management system in northern Afghanistan urban resilience: what does it mean in planning: a cautionary note. *Planning Theory & Practice*, *13*(2), 299–333.

EEA (2015). The European environment – state and outlook 2015 – synthesis report. European Environment Agency. Retrieved from https://www.eea.europa.eu/soer-2015/synthesis/report

Evans, G. R. (2008). Transformation from 'carbon valley' to a 'post-carbon society' in a climate change hot spot: the coalfields of the Hunter Valley, New South Wales, Australia. *Ecology and Society*, *13*(1), 39.

Folke, C. (2016). Resilience (republished). *Ecology and Society*, *21*(4), 44.

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C. S. & Walker, B. (2002). Resilience and sustainable development: building adaptive capacity in a world of transformations. *AMBIO: A Journal of the Human Environment*, *31*(5), 437–440.

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Chapin, T. & Rockström, J. (2010). Resilience thinking: integrating resilience, adaptability and transformability. *Ecology and Society*, *15*(4), 20.

Gao, J., Barzel, B. & Barabási, A.-L. (2016). Universal resilience patterns in complex networks. *Nature*, *530*(7590), 307–312.

Glaser, M., Plass-Johnson, J. G., Ferse, S. C. A., Neil, M., Satari, D. Y., Teichberg, M. & Reuter, H. (2018). Breaking resilience for a sustainable future: thoughts for the Anthropocene. *Frontiers in Marine Science*, *5*, 1–7.

Haider, L. J., Boonstra, W. J., Peterson, G. D. & Schlüter, M. (2018). Traps and sustainable development in rural areas: a review. *World Development*, *101*, 311–321.

Hassink, R. (2005). How to unlock regional economies from path dependency? From learning region to learning cluster. *European Planning Studies*, *13*(4), 520–535.

Hediger, W. (1999). Reconciling 'weak' and 'strong' sustainability. *International Journal of Social Economics*, *26*(7/8/9), 1120–1144.

Helfgott, A. (2018). Operationalising systemic resilience. *European Journal of Operational Research*, *268*, 852–864.

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics*, *4*(1), 1–23.

IAP (2018). Opportunities for future research and innovation on food and nutrition security and agriculture: the InterAcademy Partnership's global perspective. Retrieved from https://www.interacademies.org/48898/Opportunities-for-future-research-and-innovation-on-food-and-nutrition-security-and-agriculture-The-InterAcademy-Partnerships-global-perspective

IPES-Food (2016). From uniformity to diversity: a paradigm shift from industrial agriculture to diversified agroecological systems. Retrieved from https://www.ipes-food.org/images/Reports/UniformityToDiversity_FullReport.pdf

Irwin, E. G., Culligan, P. J., Fischer-Kowalski, M., Law, K. L., Murtugudde, R. & Pfirman, S. (2018). Bridging barriers to advance global sustainability. *Nature Sustainability*, *1*(7), 324–326.

James, R., Otto, F., Parker, H., Boyd, E., Cornforth, R., Mitchell, D. & Allen, M. (2014). Characterizing loss and damage from climate change. *Nature Climate Change*, *4*(11), 938–939.

Juhola, S., Glaas, E., Linnér, B.-O. & Neset, T.-S. (2016). Redefining maladaptation. *Environmental Science & Policy*, *55*, 135–140.

Julliard, R., Clavel, J., Devictor, V., Jiguet, F. & Couvet, D. (2006). Spatial segregation of specialists and generalists in bird communities. *Ecology Letters*, *9* (11), 1237–1244.

Lade, S. J., Haider, L. J., Engström, G. & Schlüter, M. (2017). Resilience offers escape from trapped thinking on poverty alleviation. *Science Advances*, *3*(5), e1603043.

Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., … Thomas, C. J. (2012). Transdisciplinary research in sustainability science: practice, principles, and challenges. *Sustainability Science*, *7*(S1), 25–43.

Mahoney, J. (2000). Path dependence in historical sociology. *Theory and Society*, *29*(4), 507–548.

Milkoreit, M., Hodbod, J., Baggio, J., Benessaiah, K., Calderón-Contreras, R., Donges, J. F., … Werners, S. E. (2018). Defining tipping points for social-ecological systems scholarship – an interdisciplinary literature review. *Environmental Research Letters*, *13*(3), 033005.

Miller, T. R., Wiek, A., Sarewitz, D., Robinson, J., Olsson, L., Kriebel, D. & Loorbach, D. (2014). The future of sustainability science: a solutions-oriented research agenda. *Sustainability Science*, *9*(2), 239–246.

Mongeon, P. & Paul-Hus, A. (2016). The journal coverage of Web of Science and Scopus: a comparative analysis. *Scientometrics*, *106*(1), 213–228.

Ngonghala, C. N., De Leo, G. A., Pascual, M. M., Keenan, D. C., Dobson, A. P. & Bonds, M. H. (2017). General ecological models for human subsistence, health and poverty. *Nature Ecology & Evolution*, *1*(8), 1153–1159.

Oliver, T. H., Boyd, E., Balcombe, K., Benton, T. G., Bullock, J. M., Donovan, D., … Zaum, D. (2018). Overcoming undesirable resilience in the global food system. *Global Sustainability*, *1*, e9.

Peters, B. G., Pierre, J. & King, D. S. (2005). The politics of path dependency: political conflict in historical institutionalism. *The Journal of Politics*, *67*(4), 1275–1300.

Phelan, L., Henderson-Sellers, A. & Taplin, R. (2013). The political economy of addressing the climate crisis in the Earth system: undermining perverse resilience. *New Political Economy*, *18*(2), 198–226.

Pierson, P. (2000). Increasing returns, path dependence, and the study of politics. *American Political Science Review*, *94*(02), 251–267.

Powell, N. S., Larsen, R. K., & van Bommel, S. (2014). Meeting the 'Anthropocene' in the context of intractability and complexity: infusing resilience narratives with intersubjectivity. *Resilience*, *2*(3), 135–150.

Pradhan, P., Costa, L., Rybski, D., Lucht, W. & Kropp, J. P. (2017). A systematic study of Sustainable Development Goal (SDG) interactions. *Earth's Future*, *5*(11), 1169–1179.

Raworth, K. (2017). A doughnut for the Anthropocene: humanity's compass in the 21st century. *The Lancet Planetary Health*, *1*(2), e48–e49.

Reyers, B., Folke, C., Moore, M.-L., Biggs, R. & Galaz, V. (2018). Social-ecological systems insights for navigating the dynamics of the Anthropocene. *Annual Review of Environment and Resources*, *43*(1), 267–289.

Rockström, J., Bai, X. & DeVries, B. (2018). Global sustainability: the challenge ahead. *Global Sustainability*, *1*, e6.

Rosenschöld, J., Rozema, J. G. & Frye-Levine, L. A. (2014). Institutional inertia and climate change: a review of the new institutionalist literature. *Wiley Interdisciplinary Reviews: Climate Change*, *5*(5), 639–648.

Sartori, G. (1970). Concept misformation in comparative politics. *American Political Science Review*, *64*(04), 1033–1053.

Schipanski, M. E., MacDonald, G. K., Rosenzweig, S., Chappell, M. J., Bennett, E. M., Kerr, R. B., … Schnarr, C. (2016). Realizing resilient food systems. *BioScience*, *66*(7), 600–610.

Seppelt, R., Beckmann, M., Václavík, T. & Volk, M. (2018). The art of scientific performance. *Trends in Ecology & Evolution*, *33*(11), 805–809.

Seppelt, R., Manceur, A. M., Liu, J., Fenichel, E. P. & Klotz, S. (2014). Synchronized peak-rate years of global resources use. *Ecology and Society*, *19*(4), 50.

Standish, R. J., Hobbs, R. J., Mayfield, M. M., Bestelmeyer, B. T., Suding, K. N., Battaglia, L. L., … Thomas, P. A. (2014). Resilience in ecology: abstraction, distraction, or where the action is? *Biological Conservation*, *177*, 43–51.

Steffen, W., Richardson, K., Rockstrom, J., Cornell, S. E., Fetzer, I., Bennett, E. M., … Sorlin, S. (2015). Planetary boundaries: guiding human development on a changing planet. *Science*, *347*(6223), 1259855.

Termeer, C. J. A. M., Drimie, S., Ingram, J., Pereira, L. & Whittingham, M. J. (2018). A diagnostic framework for food system governance arrangements: the case of South Africa. *NJAS – Wageningen Journal of Life Sciences*, *84*, 85–93.

Tu, C., Suweis, S. & D'Odorico, P. (2019). Impact of globalization on the resilience and sustainability of natural resources. *Nature Sustainability*, *2*(4), 283–289.

TWI2050 (2018). *The World in 2050. Transformations to Achieve the Sustainable Development Goals.* Report prepared by the World in 2050 initiative. International Institute for Applied Systems Analysis (IIASA). Laxenburg, Austria. Retrieved from http://pure.iiasa.ac.at/15347

Unruh, G. C. (2000). Understanding carbon lock-in. *Energy Policy*, *28*(12), 817–830.

Walker, B., Holling, C. S., Carpenter, S. R. & Kinzig, A. (2004). Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society*, *9*(2), 5.

Weise, H., Auge, H., Baessler, C., Bärlund, I., Bennett, E. M., Berger, U., … Grimm, V. (2020). Resilience trinity: safeguarding ecosystem functioning and services across three different time horizons and decision contexts. *Oikos*, *129*(4), 445–456.