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Pre-paradigmatic status of industrial sustainability: a systematic review

Pre-paradigmatic
status of
industrial
sustainability

1425

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Abstract

Purpose – The purpose of this paper is to progress operations management theory and practice by organising contributions to knowledge production, in industrial sustainability, from disparate researcher communities. It addresses the principal question “What scholarly dialogues can be explicated in the emerging research field of industrial sustainability?” and sub-questions: what are the descriptive characteristics of the evidence base? and what thematic lines of scientific inquiry underpin the body of knowledge?

Design/methodology/approach – Using an evidenced-based approach, a systematic review (SR) of 574 articles from 62 peer-reviewed scientific journals associated with industrial sustainability is conducted.

Findings – This paper distinguishes three prevailing dialogues in the field of industrial sustainability, and uses Kuhn’s theory of paradigms to propose its pre-paradigmatic scientific status. The three dialogues: “productivity and innovation”, “corporate citizenship” and “economic resilience” are conjectured to privilege efficiency strategies as a mode of incremental reductionism. Industrial sustainability espouses the grand vision of a generative, restorative and net positive economy, and calls for a future research trajectory to address institutional and systemic issues regarding scaling-up and transition, through transformative strategies.

Research limitations/implications – The review is limited by the nature of the inquiries addressed in the literatures by specific researcher communities between 1992 and 2014.

Originality/value – This study performs the first SR in the field of industrial sustainability, synthesises prevailing scholarly dialogues and provides an evaluation of the scientific status of the field.

Keywords Systematic review, Circular economy, Industrial sustainability, Sustainability-oriented innovation, System innovation

Paper type Literature review

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1. Introduction

It has become axiomatic for scholarly communities in applied science and social science schools to offer three reflections concerning the theory and practice of industrial sustainability. First, there is little consensus about the meaning attributed to the concept, second, the research priorities are underdeveloped and third there is mounting interest from disparate academic fields. One all-encompassing definition of industrial sustainability suggests that it is the “conceptualisation, design and manufacture of goods and services that meet the needs of the present generation while not diminishing economic, social and environmental opportunity in the long term” (Paramanathan *et al.*, 2004 p. 528). This draws on the influential World Commission on Environment and Development (1987) meaning of sustainable development and implies multi-level (i.e. institutional, sectoral and firm) research phenomena that are relevant to the operations and production management of sustainable goods/services and rent generation in various sectors of a global economy (Shrivastava, 1995; Walker *et al.*, 2014; Wu and Pagell, 2011). Closely associated concepts include industrial ecology (Thomas, 1997), ecological economics (Wackernagel and Rees, 1997), anthropocentrism (Purser *et al.*, 1995), cradle-to-cradle (McDonough and Braungart, 2002), sustainability transitions (Markard *et al.*, 2012), servitisation (Lightfoot *et al.*, 2013), sustainable business models (Stubbs and Cocklin, 2008) and natural capitalism (Lovins *et al.*, 1999); all of which discuss ideas cognate to the sustainability of an industrial system and propose significant discontinuity from incumbent and established ideals (Evans *et al.*, 2009), akin to a paradigmatic shift (Gladwin *et al.*, 1995).

In *The Structure of Scientific Revolutions*, Thomas Kuhn’s (1970) powerful notion of emergent new paradigms replacing their incumbents in scientific communities began to attract attention in academia. Acknowledging Boer *et al.*’s (2015) commentary on how to make a meaningful contribution to theory in operations management, we capitalise on Kuhn’s explanatory power to generate an improved understanding of the growing field of research, practice and policy making known as industrial sustainability. Whilst its origins can be traced back to the earth/environmental sciences and economic geography (Adger, 2003), industrial sustainability draws on the broader disciplines of macroeconomics, political science and political economy. Scholars in these academic traditions actively debate the reliance of western industrial development and the provision of goods and services on classical and neo-liberal philosophies that privilege economic impact (Phelps, 2007), without wholeheartedly engaging with environmental and social impacts, or so-called externalities. Industrial sustainability offers a paradigmatic departure from economic philosophies troubled by orthodox Marxian portrayals of inherent contradictions (Rosenberg, 1974). Whilst Marx was criticised for assuming the limitless supply of common property resources, his analysis does expose the need to manage all impacts for sustainable industrial development and societal progress. Foster (2015) deploys a Marxian ecology perspective (1999) to stress that humanity “is confronted with what might be called the Great Capitalist Climacteric – a period of critical transition” (p. 1), an epochal shift triggered by planetary constraints. Ecological theories and branches of (moral) philosophy that discuss environmental ethics (Stone, 2002) are being consulted to conceptualise new worldviews of western capitalism and industrial growth. To date, there has been insufficient scholarly debate on the validity of using the Kuhnian notions of paradigm and paradigm shift in this context.

Following Kuhn (1970), this paper argues that industrial sustainability – a field concerned with creating a generative, restorative and net positive economy – is yet to achieve a paradigmatic consensus, “normal science” status and a defined epistemological and methodological stance. In 2011, the UK Engineering and Physical Sciences Research Council (EPSRC) with industry announced a £5.2m investment to support a national innovation effort in industrial sustainability (CIS, 2010). The grant proposal stated that “by 2050 the global industrial system is targeted by international agreements and governments to double its output while only using 50% of current resources and generating 20% of current CO₂. This represents a new industrial revolution, requiring new approaches which

we term collectively, Industrial Sustainability” (CIS, 2010, p. 1). It further acknowledged that “Industrial sustainability is a fast-moving subject” (CIS, 2010, p. 4). This programme is pan-university, bringing together academics from engineering, business and management, industrial ecology and environmental policy schools across the UK. A Kuhnian interpretation of EPSRC’s investment signals a significant step in an emerging field of research inquiry by providing resources, legitimacy and acknowledging the role of academe in paradigm development in industrial sustainability.

The importance of industrial sustainability as a burgeoning field of inter-disciplinary research originates partly due to the need for benign operation and production systems (Elms *et al.*, 2010). Many different fundamental and applied research disciplines have taken on the challenge to help achieve this ambition. A plethora of diverse operational pathways, such as ISO14001 (e.g. Guinee *et al.*, 2010), life cycle assessment (e.g. Guinee *et al.*, 2010), the strategic sustainable development framework (e.g. Robèrt *et al.*, 2002), the cradle-to-cradle philosophy (Braungart *et al.*, 2007) and the circular economy (Park *et al.*, 2010) stress the grand vision of business sustainability, to meet the requirements of a firm’s stakeholders (direct and indirect) without compromising its capability to meet those of future stakeholders (Carroll and Shabana, 2010). So far the scientific emphasis has been on firm-level operations and production activities. However, as adjustments in business purpose and technological infrastructure follow, they will command greater institutional change and system-level innovation for a “new normal” to transpire in practice.

This paper synthesises the scientific knowledge base from different fields of research between the years 1992 and 2014 and provides an organising lens for future scholarship in industrial sustainability. Our principal question, “What scholarly dialogues can be explicated in the emerging research field of industrial sustainability?”, responds to the call for more systematic reviews (SRs) in this field (Bertels and Bowen, 2015) and is guided by Paramanathan *et al.*’s (2004) definition of industrial sustainability.

Three distinct and unifying dialogues emerge from this review: “productivity and innovation”, “corporate citizenship” and “economic resilience” in the context of industrial sustainability. A major theme that penetrates these dialogues is a preoccupation with efficiency strategies to confront the challenges presented by a linear (and one might argue unsustainable) economy, which inadvertently serves to preserve its dominant design. These strategies are concerned with reducing harm, abatement, end of pipe solutions, doing more with less and minimising the negative impacts of the existing industrial system. As such, they have been collectively termed as a mode of incremental reductionism that maintains the supremacy of the status quo. Industrial sustainability espouses the grand vision towards a generative, restorative and net positive economy, and calls for a future research trajectory to address institutional and systemic issues for scaling-up and transition. Our analysis proposes the pre-paradigmatic scientific status of industrial sustainability as a field of research – in the evolution of an industrial system in which business, civil society and government hybridise alternative transformative strategies to advance environmental and societal well-being.

2. Methodological considerations

SRs were developed in the field of medicine as an objective methodology to integrate and summarise large volumes of existing information and provide data for rational decision making (Mulrow, 1994). It is an explicit and transparent approach for locating, appraising and synthesising evidence to provide new insights on phenomena (Petticrew, 2001). Since its introduction to the domain of management and organisation studies by Tranfield *et al.* (2003), the SR has become an increasingly popular approach to the challenge of bringing together and making sense of a diverse body of evidence from a fragmented and eclectic field (Tranfield and Starkey, 1998).

2.1 SR method

This research follows Denyer and Tranfield's (2009) five steps for SR: question formulation, locating studies, study selection/evaluation, analysis/synthesis and reporting/using results.

2.1.1 Question formulation. Research scope, review question, inclusion/exclusion criteria and protocol were established following dialogue between the research team and a review guidance committee comprised of academic, librarian and industry experts. This resulted in the following review question: "What scholarly dialogues can be explicated in the emerging research field of industrial sustainability?" and sub-questions what are the descriptive characteristics of the evidence base? and what thematic lines of scientific inquiry underpin the body of knowledge?

2.1.2 Locating studies. The initial "scoping stage" of the SR distinguishes appropriate parameters, boundaries and resourcing costs, without assessing the quality of studies. To remain inclusive and harness variety in the knowledge base, the relevance criteria were initially guided by Paramanathan *et al.*'s (2004) broad definition of industrial sustainability. Scoping is by nature ad hoc and iterative and early keyword/search string pilot runs in EBSCO located 5,077 scientific papers from which a random sample of 110 items were used to extract article titles, abstracts and keyword descriptors. A process of iteration followed to distil 114 keywords and compile 11 initial search strings to perform further pilot searches. The scoping procedure was appraised by an SR advisory panel of academics with subject expertise and an expert SR librarian who advised on the inclusion of an additional 15 articles and the exclusion of four search strings that lacked relevance to the review question, or produced duplicated search results or no new results, or were considered conceptually embedded in other search strings, or contained keywords that defacto reflected the academic foci in the potential sample of journal titles and/or used terms that were considered synonymous or to have comparable meaning. Consistent with the objective of articulating scholarly dialogues in a field, successive searches were for articles published in peer review journals only. The peer review process that characterises these journals can be used as a proxy for quality evidence (e.g. Birnik and Bowman, 2007; Colicchia and Strozzi, 2012).

The final set of seven search strings consisted of 90 keywords (Table I). These search strings generated an initial sample of 33,470 articles which, following the application of inclusion and exclusion criteria that included research quality (rigour) and relevance to the review questions, was reduced to a final sample of 574 articles (Figure 1) from 62 journals[1]. These were subsequently analysed both descriptively and thematically (Thomas and Harden, 2008).

2.1.3 Study selection/evaluation. The search focused on four electronic databases, which together provide comprehensive coverage of the topic: ABI Inform, Science Direct, Scopus and Informaworld. We adopted a supplementary, multi-layered strategy including hand searching, cross-referencing, snowballing and seeking out expert recommendations to pick up relevant material not included in the electronic databases (Greenhalgh and Peacock, 2005) and filtered these according to the criteria in Table II.

2.1.4 Analysis/synthesis. This study makes use of an integrated synthesis approach (Rousseau *et al.*, 2008) which applies predetermined questions and selection criteria to identify patterns that synthesise constructs and their relationships. This flexible approach allows both descriptive and procedural knowledge to be combined. A data extraction form, consisting of first-order concepts, facilitated analysis and synthesis accordingly. Undertaken by two researchers to minimise bias, a qualitative analysis approach was adopted (Miles and Huberman, 1994; Saldaña, 2009; Gioia *et al.*, 2013), with an iterative process of analytical induction and a cycle of hierarchal axial coding, resulting in first-order concepts/constructs and second-order themes, subsequently consolidated to aggregate dimensions (i.e. thematic dialogues).

A clustering of frequently occurring data was based on key lines of inquiry identified within the title, abstract and keywords of each paper, whilst being mindful of how "industrial sustainability" is conceptualised. The first coding cycle was primarily

String number	90 keywords
String 1	Clean* Production OR Eco-Efficiency OR Material Efficiency OR Energy Efficiency OR Dematerialisation AND Manufacturing Resources OR Resource Efficiency OR Resource Productivity OR Material Productivity OR Resource Consumption OR Source Reduction
String 2	Green Company OR Green SME OR Green Business OR Business Development AND Triple Bottom Line OR Eco-Labeling OR Environmental Performance OR Product Stewardship OR Servicing OR Natural Capitalism OR Product Life Extension OR Weak Sustainability OR Strong Sustainability
String 3	Waste Minimisation OR Zero Waste OR Zero Landfill OR Pollution Prevention AND Waste Hierarchy OR Waste Prevention OR Waste Avoidance OR Waste Reduction OR Waste Minimisation OR Pollution Reduction OR Pollution Prevention OR Recycling
String 4	Environmental Management OR Environmental Assessment OR Environmental Performance OR Corporate Environmental Performance AND Environmental Performance Indicators OR Ecological Footprinting OR Sustainable Reporting OR Sustainable Development Indicators OR Environmental Indicators OR Sustainable Financial Analysis
String 5	Environmental Benign Manufacturing OR Environmental Conscious Manufacturing OR Green Manufacturing OR Sustainable Manufacturing OR Green Production OR Slow Manufacturing AND Dematerialisation OR Miniaturisation OR Eco-factory OR Eco-compatibility of Ind. Processes OR Closed-loop OR Zero Emissions
String 6	Sustainable Engineering OR Green Engineering OR Eco-Design OR Sustainable Design OR Eco-Products OR Sustainable Industrial Design AND Design for the Environment OR Design for Remanufacturing OR Design for Recycling OR Design for Assembly OR Design for Disassembly OR Modularisation OR Dismantling OR Product Recovery
String 7	Industrial Ecology OR Industrial Ecosystem OR Industrial Metabolism OR Industrial Sustainability OR Greening of Industry OR Industrial Symbiosis OR Eco-Industrial Parks Sustainable Development OR Sustainable Industrial System AND Life Cycle Analysis OR Product Life Cycle OR Life Extension OR Cradle to Cradle OR Cradle to Grave OR Product Sustainability OR Reverse Logistics OR Life Cycle Assessment

Table I.
Keywords and
search strings

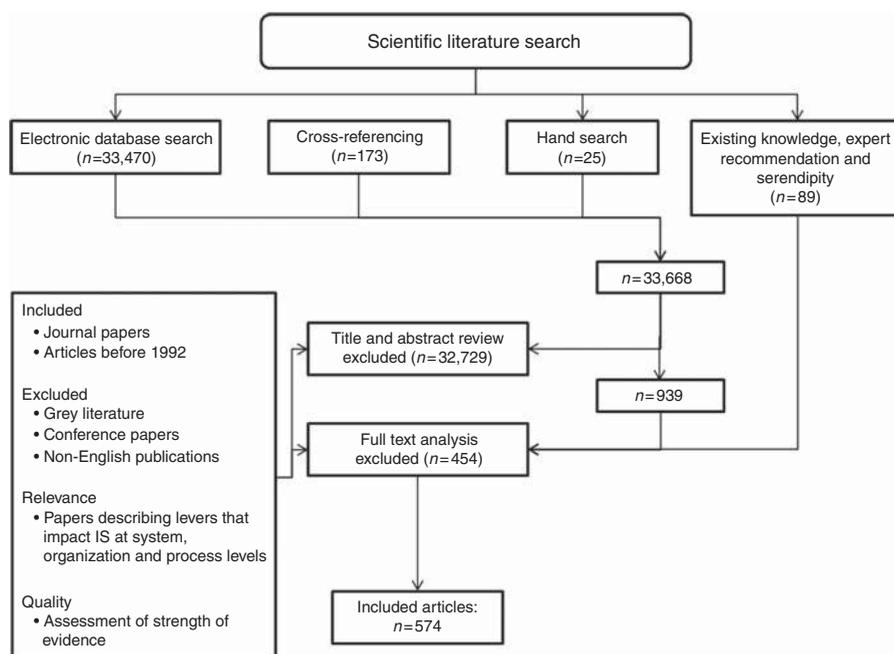


Figure 1.
Search strategy

Table II.
Inclusion/exclusion
criteria

Selection criterion	Inclusion	Exclusion
Study type	Conceptual and empirical articles	Non-English publications
Source types	Peer-reviewed journals identified via scoping study and systematic review expert panel	All other journals not listed and grey literature
Quality assessment	Originality, significance and rigour is considered world leading and internationally excellent	Originality, significance and rigour is considered international or below
Time period	Before 1992, After 2014	After 1992, Before 2014
Relevance	Articles that address research questions associated with industrial-scale economic activity about the manufacture (from design to disposal) of sustainable goods and services	Contributions with no explicit connection to industrial and economic activity, with a sole emphasis on sustainable development issues

descriptive and generated an initial set of concepts identified in the sample set of review articles. The second coding cycle helped to elicit themes (or categories) and relationships. The final coding cycle refined and allowed for higher-level abstraction, aggregation and internal validation of the resultant three dialogues.

2.1.5 Reporting/using results. In the follow sections, we present the findings in two parts, by first providing a descriptive analysis of the sample of 574 articles and second, presenting an in-depth thematic analysis to identify the prominent dialogues in the literature (Dixon-Woods *et al.*, 2005).

2.2 Descriptive analysis: characterising the sample and body of knowledge

The descriptive analysis shows that industrial sustainability research continues to attract scholarly interest internationally, is fragmented and highly distributed, yet shows some signs of advancement. Figures 2 and 3 illustrate a growing research interest in the field since 1992. An inflection point occurs around 2005/2006, after which annual publication rates accelerate (Figure 2). Empirical studies start to replace conceptual and theoretical works as the dominant output type (Figure 3), indicative of the testing of concepts/theories and growing maturity of the literature.

Reay *et al.*'s (2009) six-level evidence hierarchy posits that the strongest evidence is found in randomised controlled trials and meta-analyses and the weakest is in opinion pieces. The primary concern is with the content of research dialogues within the industrial sustainability field rather than with quality attributes. Nevertheless, mapping the 574 articles against Reay *et al.*'s (2009) hierarchy in Figures 4-6 shows that theoretical/conceptual works lack relative strength of evidence as most are non-SRs and later, a larger proportion of multi-case and small-sample empirical studies begin to emerge. Collectively,

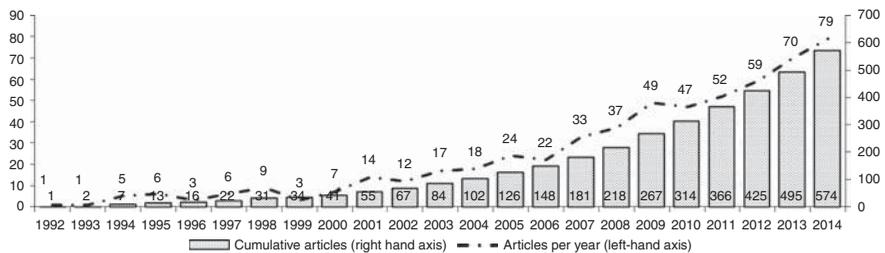
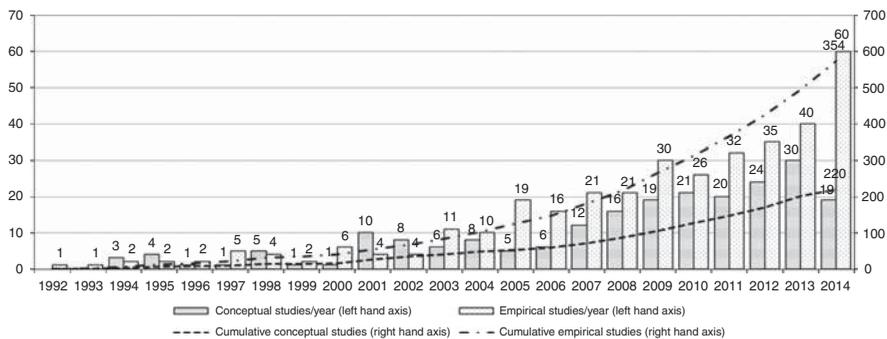
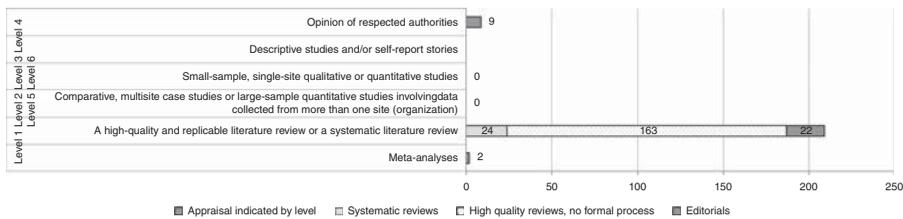


Figure 2.
Article distribution
per year

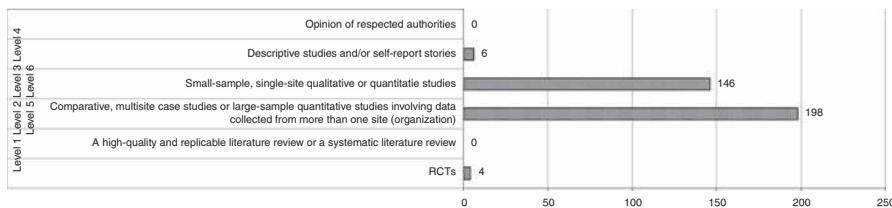
Note: $n = 574$



Note: $n=574$



Notes: $n=220$. The authors have included other high-quality non-replicable reviews ($n=163$) in Level 2



Note: $n=354$

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Figure 3. Evolution of conceptual and empirical papers

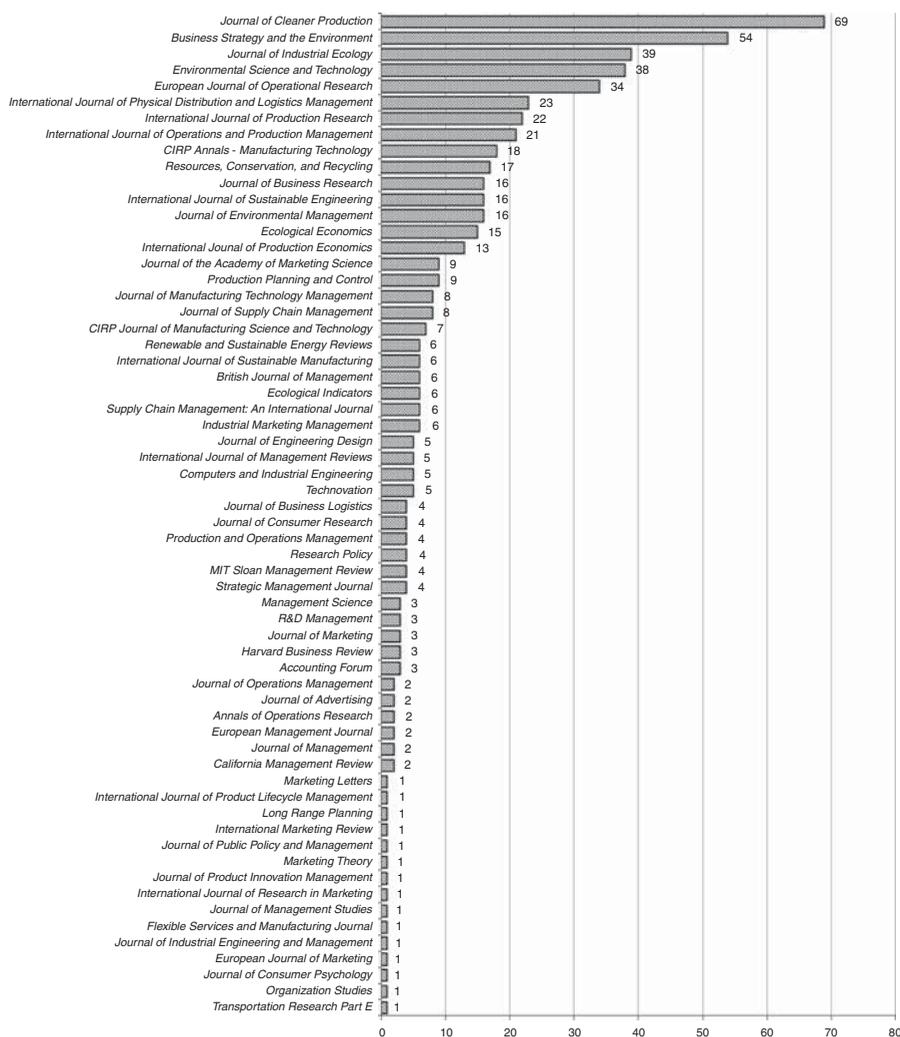
Figure 4. Quality appraisal of theoretical/conceptual papers based on Reay *et al.* (2009)

Figure 5. Quality appraisal of empirical papers using Reay *et al.* (2009)

these figures are illustrative of gradual knowledge production and early signals of convergence on ontological and methodological issues in the field.

Research activity is widely distributed, as lead authors are located in 41 countries (Figure 7), with most originating in developed economy countries, particularly the USA (151 articles) and UK (72 articles). In terms of institutional output (determined by lead author affiliation), articles can be credited to 366 different institutions of which 323 published two or fewer articles, indicating a highly distributed interest in the academic community. The small number of institutions that have published more than five articles (Figure 8) suggests that centres of excellence might be emerging.

Our sample consists of 574 articles drawn from 62 different journals. Of these journals (including *IJOPM*), 15 account for 411 (72 per cent) of the included articles, an emergent core or consolidation of interest, but a long and distributed “tail” of activity (Figure 9). Publications within journals are focused on operations and production, management and environmental and industrial ecology. A total of 24 per cent of the journals have engaged with 71 per cent of the academic conversations on the industrial sustainability topic.



Note: $n = 574$

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Figure 9.
Article distribution
by journal

A closer qualitative analysis of the research literatures illuminate overarching dialogues which provide the evidence to support the proposition that science in the field of industrial sustainability shows some signs of progress beyond the pre-paradigmatic phase. The following section presents a thematic analysis of this data set and discusses the dialogues in more detail.

3. Thematic analyses: dialogues in industrial sustainability

The thematic analysis exposes the high-level dialogues taking place in the industrial sustainability literature. The thematic analysis demonstrates three distinct dialogues (Figure 10): “productivity and innovation”, “corporate citizenship” and “economic resilience”.

3.1 Productivity and innovation

The productivity and innovation dialogue arises from lines of inquiry into product (re) design, material utilisation and optimisation strategies, and rethinking “value creation” in market propositions at a product and process level. This dialogue comes predominantly from within the operations and production research community in engineering schools and comprises 394 articles or 69 per cent of the sample (Figure 11).

3.1.1 Product (re)design. Product (re)design may include the substitution of toxic for non-toxic materials, dematerialisation efforts, green chemistry and biomimicry following a consideration of the entire product life cycle in a systems approach to design (Dobers and Wolff, 1999; Tabone *et al.*, 2010; Fiksel, 2003). The eco-design of products and/or related services is inextricably linked to the design of future production processes (Ilgin and Gupta, 2010; Luttrupp and Lagerstedt, 2006) increasingly enhanced through the use of new technologies (Winkler, 2011). For example, enhancements in integrated vehicle health management, telematics and remote condition monitoring can sense the real-time performance of products in use and ensure that only the required (and not excessive) maintenance operations are performed (Benedettini *et al.*, 2009). Redesign efforts towards the sustainable production (Geldermann *et al.*, 2007) can improve materials utilisation and optimise processes, but are often incremental enhancements due to path dependencies and the legacy costs of capital equipment and embodied carbon (Branker *et al.*, 2011).

3.1.2 Material utilisation and process optimisation. Significant research efforts focus on minimising the negative impacts of products has led to the optimisation of material processing activities in terms of recycling, reuse and recovery of energy and materials in production systems. Recycling involves “the collection and treatment of waste products for use as raw material in the manufacture of the same or a similar product” (Glavic and Lukman, 2007, p. 1877). Reuse is the multiple use of materials and energy to reduce product and process waste via closed material loops (Jayal *et al.*, 2010; Sundin *et al.*, 2009; Winkler, 2011). This revalorisation of outputs from technical metabolisms (Braungart *et al.*, 2007) is achieved with for example “industrial symbiosis” and “remanufacturing” (Boons *et al.*, 2011; Despeisse *et al.*, 2012) which re-channel the waste as raw material in the production of same/similar products. Prior to reuse, there may be a process of recovery, to seek materials in waste streams for purposes other than their original use. The aim is to safeguard discrete valuable resources with simpler dismantling of products and thus retrieval of embedded materials (Dodson *et al.*, 2012).

3.1.3 Sustainable value. Our final sub-theme moves the dialogue from incremental progress concerning products and operational processes to the need for discontinuous efforts for sustainable value creation, through new business models (Bocken *et al.*, 2014). Similar to the cradle-to-cradle philosophy (Braungart *et al.*, 2007), the circular economy concept seeks the end of the “linear economy” and to promote sustainable growth using closed-loop production

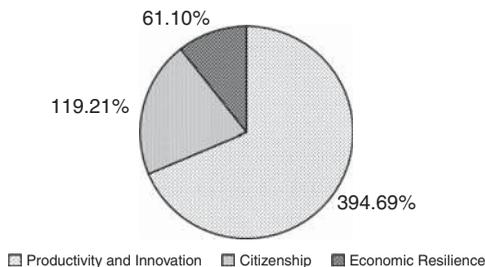
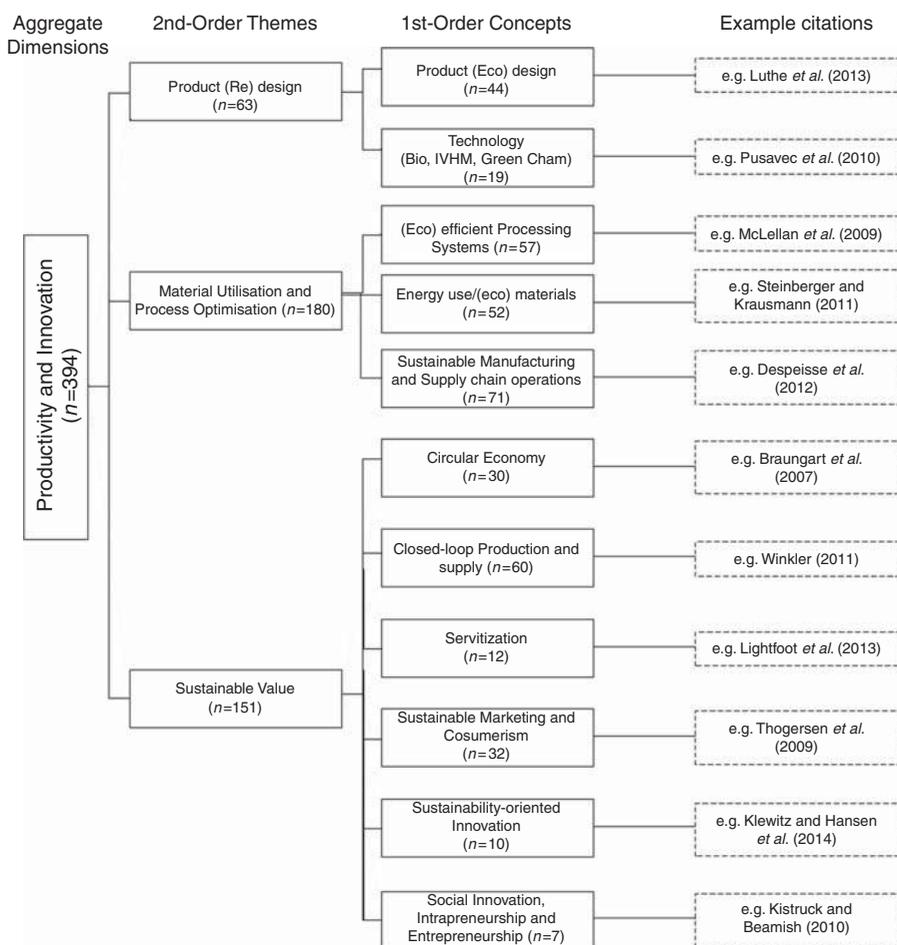


Figure 10.
Discourses in
industrial
sustainability

Note: $n = 574$



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Figure 11.
Productivity and
innovation

systems geographically distributed at local and global levels (Amin and Zhang, 2013; Geng *et al.*, 2012). The manufacturing industry trend to servitisation and product-service systems focuses on extracting sustainable value from “product-in-use” (including notions of the sharing economy) with the implications of less product and greater service provision. This offers performance-based contracting opportunities for the delivery of advanced services designed around a central product (Lightfoot *et al.*, 2013; Mont, 2002). These philosophies aim to ensure functioning within planetary ecological systems, maintaining higher stocks of scarce resources, and ensuring political and economic stability within tolerable variations (Thomas and Graedel, 2003). The sustainability-oriented innovation (Klewitz and Hansen, 2014) and social intrapreneurship (Kistruck and Beamish, 2010) literatures illustrate the individual to system-level range of transition necessary.

In conclusion, the productivity and innovation dialogue predominantly emphasises continuous and incremental change to facilitate reductions in undesirable corporate impacts, through (eco)-efficiency agendas for improved sustainability performance. However, Braungart *et al.* (2007, p. 1338) note that this presupposes “a system of production and consumption that inevitably transforms resources into waste and the earth into a graveyard.”

Whilst addressing the environmental impacts of industrial activities, this approach mostly ignores the social impacts that are a crucial part of diverse, efficient, adaptive and cohesive systems at product, firm, ecological and socio-economic system levels (Fiksel, 2003). Gutowski *et al.* (2005) call for future research to address this deficiency and to accommodate such linkages and related research questions.

3.2 Corporate citizenship

The corporate citizenship dialogue originates principally from the applied social science field of management research in business schools and comprises 119 articles or 21 per cent of the sample. Lines of inquiry focus on the wider business-in-society issues at organisational or extended enterprise levels (Figure 12) and encompass the “business case” and “ideological issues” of corporate citizenship.

3.2.1 Business case. The business case for corporate social responsibility (CSR) “is concerned with the primary question of how organisations benefit tangibly from engaging in CSR policies, activities and practices” (Carroll and Shabana, 2010, p. 87; Eccles *et al.*, 2010). It integrates the needs, aspirations and intrapreneurship of employees in the workplace to promote equity, development and well-being (Liu *et al.*, 2012); adopts environmental ISO14001 standards (Kerret, 2008) and develops sustainable marketing strategies to promote environmental and social benefits and combat the negative impacts of consumerism (McDonald and Oates, 2006). As a complement to these individual and organisational-level inquiries, we also observe multi-organisation-level research on sustainable supply chains. For example, researchers are addressing significant issues either through market externalisation via extended supplier responsibilities/relationships (Svensson, 2007), or by internalising social and environmental impacts through sustainable procurement practices that support local communities (Meixell and Luoma, 2015). This is partially a reflection of the functional divisions in organisations (e.g. marketing, procurement, production and R&D) that are incorporating sustainability into existing routines. Unfortunately, the net effect often amounts to an “add-on” rather than a “designed-in” approach to such functional divisions, even if intentions may be more ambitious.

The democratisation of environmental and social issues engages organisations with civil society, not for profit and governmental organisations (Matten and Moon, 2008). Collaborative business-society linkages help organisations to accommodate various stakeholders’ concerns, such as climate stabilisation, water purification, soil remediation and reproduction of plants and animals (Rueda-Manzanares *et al.*, 2008; Perrini and Tencati, 2006; Dyllick and Hockerts, 2002). This inevitably draws attention to the role of

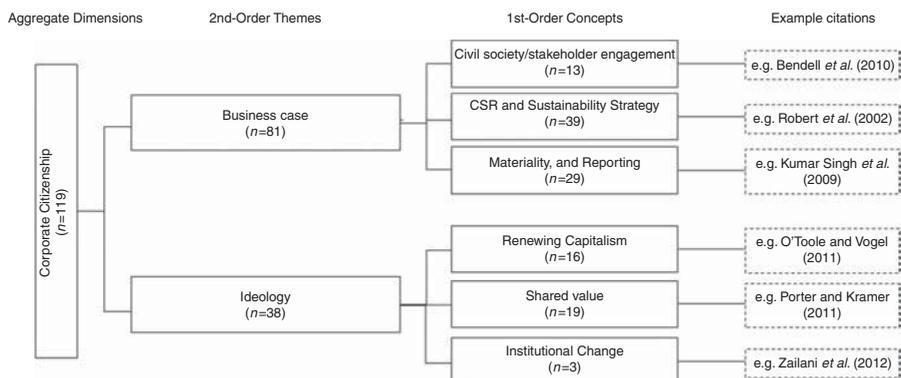


Figure 12.
Corporate citizenship

corporate governance to resolve the potential divergence of interests between stakeholders, investors and executives (Banerjee and Bonnefous, 2011; Battilana and Lee, 2014; Hahn *et al.*, 2014; Jay, 2013).

Assessing impacts (or materiality) is a “direct way of utilising metrics on various activities that can reduce the throughput of resources and energy in a given process” (Robèrt *et al.*, 2002, p. 205) and often involves carbon and greenhouse gas emissions analysis and product-embodied carbon and water footprinting analysis (Gutowski *et al.*, 2011; Tabone *et al.*, 2010). Environmental performance assessments can also be considered synonymous with direct social impacts used to measure adequate working conditions, diversity and equal opportunities, relations with the community, compliance with social policy, consumer health and safety and human rights issues (Molina-Azorin *et al.*, 2009; Crane, 2013).

Proposals for the convergence of social and environmental issues with other economic impact assessments such as the integrated reporting methodologies are also being made (Delmas and Blass, 2010; Hubbard, 2009; Niemeijer and de Groot, 2008). Firms are increasingly participating in competitive and voluntary endeavours such as the FTSE for Good Index, the Dow-Jones Sustainability Index and the Global Reporting Initiative, which seek greater disclosure, transparency and accountability with regard to environmental and social performance. This creates opportunities for the social (responsible) investor community, but some activists are calling for an end to voluntarism and are demanding greater standardisation and mandatory/legislative inducements regarding the assessment and reporting of sustainability performance (Lamberton, 2005).

3.2.2 Ideology. Finally, a stream of research inquiry concerning the contemporary relevance of ideologies that fortify western business operations is becoming apparent. More specifically, the dominant capitalistic economic paradigm (Barton, 2011) is questioned, with an argument for corporations to create economic, environmental and social value. This is characterised by the notion of “shared value” (Porter and Kramer, 2011), which encourages businesses to improve the conditions of the communities they operate in, whilst simultaneously enhancing their own competitiveness. Complementary notions of responsible capitalism and conscious capitalism (O’Toole and Vogel, 2011) advocate high governance and ethical standards and a focus on long-term sustainable economic growth for society. These debates are re-engaging academic conversations about organisation purpose and the business-society relationship (Hollensbe *et al.*, 2014). While some of the big corporate players, like Puma and Rolls Royce, are embracing new business models sensitive to such ideas, transition will demand strong engagement between business, civil society and government to facilitate the necessary institutional-level changes (Bessant, 2013; Lettice *et al.*, 2012) via national policies.

To summarise, there are propositions from management and organisation theorists to examine the contemporary relevance of current ideologies and worldviews on corporate citizenship in future investigations. For example, a dynamic capabilities perspective can help firms minded to operate within ecological boundaries and to “encompass the economic, legal, ethical, and discretionary expectations that society has of organisations at a given point in time” (Carroll and Shabana, 2010, p. 89). Hart (1995) proposed a natural-resource-based view of the firm strategising around pollution prevention, product stewardship and sustainable development for sustained competitive advantage. At the organisation level, researchers are calling for future research to investigate organisational purpose (Hollensbe *et al.*, 2014), new structural forms, i.e. “hybrid organisations” that transcend institutional boundaries (Battilana and Lee, 2014) and distributed or open innovation that encourages cross-sector collaborations (Holmes and Smart, 2009). This has implications for social movement and institutional-level change, which the economic resilience dialogue is beginning to address.

3.3 Economic resilience

The economic resilience dialogue concerns itself with the underlying assumptions of existing western liberal economic systems and represents 61 articles or 10 per cent of the sample. It focuses on the transformative potential of such ideas at an institutional level and led by the industrial ecology and economics policy research communities (Figure 13). Lines of inquiry focus around the notions of “natural capitalism” and “sustainable industrial systems”.

3.3.1 Natural capitalism. Natural capitalism connects human institutions with the flow of natural cycles within eco-system services that offer useful resources for economic activities (Fiksel, 2003). While these resources have been excessively used (Stern, 2006), their ongoing depletion is countered by organisations seeking to mainstream the economics of nature (TEEB, 2010) and internalise environmental impacts through environmental policy and other economic instruments. Wijen and van Tulder (2011) propose four dynamic environmental strategies that align different regulatory/market configurations for multinationals firm from developed and emerging markets.

3.3.2 Sustainable industrial systems. Future archetypal forms of sustainable industrial systems remain unclear, as do the range of transition pathways and associated challenges. Nevertheless, there is a growing recognition of the need to monitor resources in the context of a global R&D infrastructure and consider changes of paradigms and technologies for a sustainable industrial future (Allwood *et al.*, 2011).

Environmental policy instruments, such as resource and waste (e.g. carbon) taxes or regulations banning undesirable corporate behaviours, are concerned largely with promoting material and resource efficiency (Massarutto, 2014). Information-based policy instruments include certification and standards, preferential purchasing, voluntary programmes, subsidies and incentives, taxes and charges and bolstering research and development initiatives. However, it remains unclear which policies are most effective (Chen and Monahan, 2010). Concerns with environmental regulation revolve around issues of compliance and stringency in enforcement of local or domestic regulation (Herrmann and Thiede, 2009; Lefebvre *et al.*, 2003), and attracting political pressure from external stakeholders about the lack of clean technology alternatives (González-Torre *et al.*, 2010). Lobbying for less aggressive legislation is one approach to influence carbon emission baselines, as sometimes deployed by energy intensive industries (Allwood *et al.*, 2010). Industry regulation in developing countries is described as potentially ineffective owing to insufficient environmental infrastructure (e.g. effective sewage systems) and the financial and human resource constraints that affect compliance levels (Massoud *et al.*, 2010).

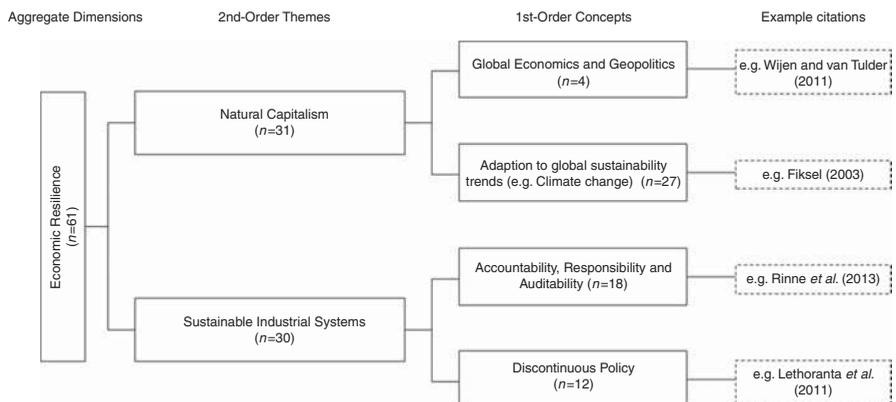


Figure 13.
Economic resilience
themes

Regulation via voluntary policies may be possible depending on the maturity of a specific political economy.

Regulation and policy making highlight the important role of government institutions in raising awareness of environmental issues by bringing together for-profit and non-profit actors (Moffat and Auer, 2006). Provided that an infrastructure supports environmental resource management, strong legislation is acknowledged to encourage pollution prevention and environmental impact assessment (Niemeijer and de Groot, 2008; Sarkis, 1995). This is exemplified in recycling-related waste policy debates (Dahmus and Gutowski, 2007; Lauridsen and Jørgensen, 2010)[2] and proposals to use production-related design policies (Kempener *et al.*, 2009; Gibbs and Deutz, 2007; Kjaerheim, 2005). Punitive- and incentive-based policy instruments are mechanisms that drive eco-friendly technology transfer and innovation through the promotion of foreign direct investment (Letchumanan and Kodama, 2000) and technological innovations with taxation and regulation strategies that reduce rebound effects (Herring and Roy, 2007).

Policies that support eco-efficiency imply adaption within well-defined incumbent industrial conditions and the technological lock-in imposed by legacy systems. Calls for future research suggest that they postpone the onset of broader systemic changes that are inevitably destabilising and generate ambiguity and demand new policies (Seebode *et al.*, 2012). Even in light of legislative measures, such as the UK's Climate Change Act (2008), such calls for systems innovation research harbour institutional contradictions. For example, the new collaborations between Greenpeace (2014) and coalitions of environment and health NGOs show that whilst shale gas fracking is politically supported, it runs against the EU's commitment to achieving a high level of environmental protection based on precautionary principles. Lambertson (2005) argues for the inclusion of non-conventional accounting metrics (for e.g. happiness and well-being) and the NEF (2014), an independent UK Think Tank, is paving the way for better accounting methods for more sustainable economic conditions by offering fresh radical ideas to policy makers.

4. Thomas Kuhn's theory of paradigms: a valuable analytical lens

Considering industrial sustainability as a new economic paradigm merits discussion for three reasons. It allows scholars, first, to reflect on the distinctions between the presumed old and new paradigms, second, to gauge some perspective of the coexistence of evolutionary and revolutionary change and finally it affords the opportunity to venture into the realms of ontology and epistemology and inform fellow academics of the nature of the knowledge base in an emerging research field. In what follows, the research findings are discussed in relation to Kuhn's theory of paradigms, credited for its explanatory power by operations management scholars (Boer *et al.*, 2015).

4.1 *Progress in science and its implication for industrial development*

Kuhn's curiosity was captured by trying to understand the circumstances that helped to facilitate new scientific discoveries. It became apparent to him that most scientific work was not focussed on exploring novel insights, but rather exploiting the standard way of looking at a (research) problem or phenomenon at any particular point in time. Scientists privilege their attention on significant problems and potential solutions that adhere to a specific paradigm that informs the way science practice is conceptualised and operationalised. Scientists build on a common worldview without starting anew with each research programme. A new paradigm has to compete with rival theories and the instruments used to solve the significant problems of a scientific era.

Our research findings suggest that the adherence to an economic paradigm, informed by classical and neo-classical economic theories of industrial development, is under scrutiny,

with the emergence of notions such as conscious capitalism (O'Toole and Vogel, 2011). A paradigm encapsulates "law, theory, application and instrumentation altogether" (Kuhn, 1970, p. 10) and as this inspection intensifies, entire social structures and systems in which the practice of science takes place are dismantled over time.

Kuhn (1970, p. 175) used the term paradigm to refer to "the entire constellation of beliefs, values and techniques shared by members of a given community" and one component, the "exemplar" has great importance. An exemplar is a problem-resolution framework used to identify and solve inquiries of relevance and significance to a particular paradigm. Collectively, they become the commonly accepted and unquestioned ideals for students of a specific discipline and members of a scientific community and thereby act as an important mechanism for scholarly community building and capacity development.

Kuhn's notions of paradigm transition or shift suggest that scientific work continues on significant problems within an incumbent paradigm until enough "anomalies" or effects that do not fit or adhere with the paradigm's predictions have arisen to create a "crisis" state. The existing paradigm remains intact until a new one emerges which can attract the attention of a critical mass of researchers to build a feasible alternative. A fledgling paradigm can explain not only the majority of the problems that the old paradigm could, but also those anomalies that the old one could not. As a result, the old and new paradigms become incommensurable, as they are established on different assumptions and irreconcilable foundations. The new paradigm resists amalgamation, assimilation and compromise and this conflict is the path to resolution by establishing dominance and avoiding subordination (Jackson and Carter, 1991).

In the field of industrial sustainability there are anomalies (i.e. so-called global challenges such as climate change, soil degradation, water insecurity and wealth inequality) that the current liberal economic paradigm cannot predict or explain and these have become the problems for scientists predominantly in the first dialogue "productivity and innovation" to solve. Whilst the incumbent paradigm remains largely intact, it is under strain as research, practice and policy communities begin to surface future exemplars of industrial sustainability. Paradigmatic change gathers momentum at multiple levels and the "exemplar" level is crucial because it disputes the contemporary relevance of an existing paradigm at "ontological" and "sociological" levels (Masterman, 1970).

Kuhn saw scientific progress as moving through a series of distinct stages, and following a fluid period of emergence, a science eventually achieves a state of "normal science". This new status allows it to become a dominant paradigm, which informs future practice in science as opposed to singular theories or discoveries by individual scholars, and is the origin of scientific change and ultimately revolution. The second dialogue "corporate citizenship" questions some of the premises and fundamental beliefs underpinning a liberal economic paradigm and the corporations it inhabits. In doing so, it advances understanding at a "sociological" level by encouraging fellow scientists to be more critical about the assumptions buttressing mainstream theory and professional practice. It is not until the third dialogue, "economic resilience", that ontological and metaphysical deviations are proffered in accordance with the anomalies of the incumbent industrial paradigm. The thematic analyses confirm the supremacy of a liberal paradigm that has guided western industrial development over more critical perspectives (e.g. Marxian Ecology). A growing multi- and trans-disciplinary community of academics are beginning to challenge the status quo, in light of global sustainability challenges. They are advocating alternative paradigms about industrial development and its servitude to society, and engaging in political debate for institutional reform. The launch of the UK EPSRC Centre for Industrial Sustainability is a symbolic and substantive measure in the process of legitimising a new paradigm. The Centre informs institutional-level changes through their innovation policy work, via The Government Office

for Science “The Future of Manufacturing: a new era of opportunity” report (2013) and engagement with The All-Party Parliamentary Manufacturing Group and Innovate UK.

This paper argues that pre-paradigmatic scientific change is evident where “anomalies” in industrial development are being experienced on a local and global scale, and are leading academic communities to intellectualise new paths to sustainable progress. These anomalies lead us to new exemplars that become the “spine” of normal science (Colclough and Horan, 1983) – that is to say a future normal – in which industrial development is generative, restorative and net positive. Scholarly adherents operating at the forefront of this new paradigm are already building a cohesive community and “consensus about the most important research topics and questions and the best ways of trying to analyse” Rainey (1994, p. 42).

5. Concluding remarks, limitations and implications

This paper describes and synthesises the scientific knowledge base on industrial sustainability drawing from applied academic fields within engineering, business and management, industrial ecology and environmental policy schools. It analyses 574 scientific papers from 62 international peer-reviewed journals between 1992 and 2014. We observe from a sub-sample of the literature published following the end of our review period (i.e. in 2015 and 2016) the continued predominance of the identified dialogues, the maintenance of the field’s pre-paradigmatic status, but a considerable growth in the volume of literature concerning operations and production management (Hartmann *et al.*, 2015; Tukker, 2015; Naor *et al.*, 2015; Longoni and Cagliano, 2016; Adams *et al.*, 2016; Bansal and Song, 2016; Mejias *et al.*, 2016; Wang *et al.*, 2016; Wilhelm *et al.*, 2016; Kim and Davis, 2016; Bolton and Hannon, 2016).

The descriptive analysis shows that this body of knowledge has been growing over the past 20 years, but remains concentrated in a relatively small number of universities. The field is fragmented and dispersed amongst scholarly communities and lacks maturity as it begins to move outside conceptual and theoretical developments towards empirical fieldwork. More specifically, the thematic analysis identifies three distinct and unifying dialogues in the literatures: “productivity and innovation”, “corporate citizenship” and “economic resilience”.

Lines of inquiry in the “productivity and innovation” dialogue engage the operations and production research communities with their strong focus on material and resource utilisation strategies primarily at a product and process level. In the second dialogue, “corporate citizenship”, inquiries principally engage the business and management community on the ideological shift required for sustainability efforts at an organisational and extended enterprise level. Finally, the “economic resilience” dialogue engages the industrial ecology and economics policy communities around notions of natural capitalism and sustainable industrial systems and their transformative potential at an institutional level.

We have utilised Kuhn’s paradigm theory as an analytical frame to understand meta-level phenomena that underpin developments in knowledge production. We propose that if we consider the dialogues collectively, they present a mounting readiness in the field of industrial sustainability to reach beyond pre-paradigmatic progress. Each of the three dialogues operates in accordance with Masterman’s (1970) multi-level Kuhnian evaluation at exemplar level, sociological level and ontological level. However, there are particular emphases that are noteworthy. For instance, the “productivity and innovation” dialogue galvanises scholars to attend to the anomalies which are being experienced within the existing economic paradigm (at exemplar level). The “corporate citizenship” dialogue converses on a broad front (i.e. across many business and management sub-disciplines) demonstrating a greater sociological level effort. Finally, the “economic resilience” dialogue stimulates new research questions for future studies and thereby functions at an ontological level. These dialogues collectively provide evidence for an “incremental reductionist”

approach to industrial development. In this context, efficiency strategies illustrate much adaptive organisational capacity, yet alone can stifle the system and institutional-level innovations required to nudge pre-paradigmatic progress to a “new normal” state for future industrial development. Ultimately, evolution will demand transformative strategies for scaling-up and transition to co-exist, which will re-write the rules of engagement in a generative, restorative and net positive economy. The UK Government’s new Department for Business, Energy and Industrial Strategy, which includes the ministerial team responsible for energy and climate change, signals an interventionist approach to industrial strategy in its Green Paper (January, 2017).

5.1 Limitations and implications for future research

The SR tries to minimise bias in literature reviews by adopting a transparent methodology, thus lending itself to replicability and future extension by fellow researchers. It is not without its limitations (Bartolucci and Hillegass, 2010) and Learmonth and Harding (2006) suggest that its practitioners can become more interested in the mechanics of the process, such as the selection of studies, methods of analysis, interpretation of heterogeneity and generalisation and application of results – rather than the content of sources of material collected. The present study addresses this issue, not by diminishing the importance of process, but by privileging the content of the body of knowledge as a central concern.

Through the descriptive and thematic analysis of the industrial sustainability literature, three clear dialogues taking place within and across academic fields have been identified. The field of industrial sustainability remains pre-paradigmatic, and has not yet become settled or reached maturity, as illustrated in the particularistic nature of findings rather than universalistic standards. For example, all three dialogues focus on incremental advancement towards industrial sustainability goals in their specific research domains and espouse the need for more discontinuous change and transformation strategies. However, peer community terminology is used to discuss similar research phenomena and so for instance, in the productivity and innovation dialogue there is much deliberation of “closed-loop production systems” which is relevant to discussions concerning “sustainable value” in the corporate citizenship dialogue; which is akin to the need for a new form of “capitalism” that privileges closer interdependency between business and society in the economic resilience dialogue. There are therefore similar inquiry goals for distinct research phenomena and levels of analysis. We identify this coalescence at lower levels of analyses (i.e. at product, process and organisational levels) as partial evidence for the pre-paradigmatic status of industrial sustainability that precedes more ambitious research agendas situated at higher levels of analyses (i.e. institutional and system levels).

Whilst analysis of the literatures is constrained to the timeframe of 1992-2014, it provides some evidence for the pre-paradigmatic status of the field of industrial sustainability. The substantial body of theoretical works and growing small-scale empirical studies, which are characteristically fragmented and eclectic in nature (Tranfield and Starkey, 1998; Bryman, 2006), presented a range of processual SR challenges – in particular quality assessment and synthesis – different from those in the fields in which the practice first emerged. The challenge of parsimoniously synthesising patterns of dialogue within a cross-disciplinary body of knowledge covering 574 primary studies should not be under-estimated but, by doing so, we have been able to establish the current state of knowledge and opportunities for future research endeavours and respond to the principal research question concerning the “research dialogues” that can be explicated in the emerging field of industrial sustainability. Future research may consider complementary methods such as citation, network and bibliometric analyses (see e.g., Fahimnia, Tang, Davarzani and Sarkis, 2015; Fahimnia, Sarkis and Davarzani, 2015) to further investigate the nature and structure of the dialogues uncovered by this study.

Notes

1. Full lists available on request from the authors.
2. This research relates to a broader body of work on sustainability transitions in the *Journal Research Policy*.

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