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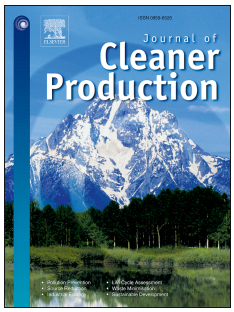

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PII: S0959-6526(17)32510-6

DOI: 10.1016/j.jclepro.2017.10.201

Reference: JCLP 10993

To appear in: *Journal of Cleaner Production*

Received Date: 29 January 2017

Revised Date: 11 September 2017

Accepted Date: 18 October 2017

Please cite this article as: Sullivan K, Thomas S, Rosano M, Using industrial ecology and strategic management concepts to pursue the Sustainable Development Goals, *Journal of Cleaner Production* (2017), doi: 10.1016/j.jclepro.2017.10.201.

Using industrial ecology and strategic management concepts to pursue the Sustainable Development Goals

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Abstract

The subjectivity, complexity, and often competing interests of sustainable development have limited the effectiveness of integrating these important ideas into mainstream business strategy. With the adoption of the UN Sustainable Development Goals (SDGs) in January 2016, there are now global sustainability benchmarks that apply across diverse sectors and national contexts, allowing public and private organizations to orient and evaluate their activities, strategies, and business outcomes. However, it is not directly apparent where the advantage for business lies in pursuit of these actions within the prevailing economic paradigm, highlighting the need for new analytical frameworks and tools. Industrial ecology (IE) has been successfully used in engineering practice for decades and has been suggested as a method that can provide the concepts and methods necessary to bridge the gap between traditional business practice and sustainable development. To test this, literature bridging the fields of industrial ecology, business strategy, and sustainable development was collected and analyzed using the textual analysis software Leximancer™. The analysis showed that while the SDGs are primarily aimed at the national level, they also hold relevance for business through innovation, partnerships, and strategic positioning, inter alia. The analysis found that the integration of IE and business strategy is highly relevant for three of the SDGs, but captures elements of all 17 to varying degrees. IE has a strong focus on innovation and its potential in new markets, products, and business models. IE is also consciously aimed at the efficient use of energy and resources, ideas that are relevant to mitigating, adapting, and building resilience in a changing future, but are also relevant to traditional concepts of business strategy and competitive advantage. This paper shows that through the combination of IE and strategic management theory, commercial organizations can positively contribute to the Sustainable Development Goals while building competitive advantage.

Highlights

- Systematic review of literature with a thematic and conceptual analysis using Leximancer™.
- Industrial ecology principles are shown to lead to competitive advantage in line with Sustainable Development Goals.
- The study establishes a baseline for quantitative analysis of the strategic benefits of IE principles.

Keywords

Global goals; text mining; Leximancer; business; competitive advantage.

Using industrial ecology and strategic management concepts to pursue the Sustainable Development Goals

1. Introduction

In September 2015 the international community adopted the Sustainable Development Goals (SDGs), to address global challenges in health, education, social equity and justice, economic security, and environmental issues. The SDGs have been developed by the United Nations as a template for sustainable devleoment globally, and are part of a wider 2030 Agenda that build on the Millenium Development Goals set in 2000.The SDGs came in to force on 1 January 2016, and while not legally binding, offer a pathway for countries to mobilize efforts to end poverty, address climate change, and secure equitable livelihoods for all people (Open Working Group of the General Assembly on Sustainable Development Goals, 2015). The SDGs establish not only 17 goals, but 169 specific targets, indicators, and metrics of sustainability across a wide range of sectors, providing practical guidance for public and private organizations (United Nations, 2015). While the goals and targets are important indicators of success, specific examples of activities that directly and indirectly support the delivery of the SDGs remain unclear, especially for the business sector, suggesting a need for research that demonstrates how businesses can support these sustainability targets within the context of their commercial priorities and activities (cf. Byrom et al., 2014; Hoffman, 2014).

The economic benefits of business activities have improved prosperity and living conditions around the world. At the same time, many of these activities have directly and indirectly led to negative impacts including environmental damage and social inequality. With a growing imperative for large-scale societal transformations towards sustainability, it is evident that traditional business thinking is not able to effectively deliver the changes that are required, and is often continuing to contribute to the creation of further problems and reinforcing unsustainable activities (Geels and Schot, 2007; Westley et al., 2011). However, the nature of business is gradually changing, with increasing calls for commerce to be transformed into an engine of sustainable development through corporate citizenship, social entrepreneurship, and pro-environmental behaviors (Abram et al., 2016; Bayon and Jenkins, 2010; Hart et al., 2003; Marcus et al., 2010; Rahdari et al., 2016; Sutton-Grier et al., 2014; Westley et al., 2011). The traditional position that the relationships of society and the environment to the firm were those of client and (limitless) resource provision and waste disposal (e.g. Porter, 1979; Teece et al., 1997; Wernerfelt, 1984) have shifted, to a view where social licence to operate is critical to corporate survival, and the firm can derive competitive advantage from interaction with environmental management activities (Hart, 1995; Hart and Dowell, 2011). These changes are also evident in the movement towards sustainable materials programs and supporting policy programs incorporated in circular economy principles (Dentchev et al., 2016; Silva et al., 2015) and industrial symbiosis models (Rosano and Schianetz, 2014).

However, while organizational and technological innovations are disrupting incumbent actors in many areas, the integration of environmental and social aspects of sustainability in profit-oriented commercial activities remains elusive (Dentchev et al., 2016), suggesting that further evolution in business management strategy is necessary. Strategic thinking has reached the stage where stakeholder benefits and sustainability outcomes are intimately connected; new business philosophies and operational strategies that emphasize a more holistic approach to commerce help firms understand and explain not only how value is captured, but how it is created, and how extra value can be obtained by increasing focus on social and environmental outcomes (Baldassarre et al. 2017; Bocken et al. 2015; Zott et al, 2011).

Many organizations, including mining and resource companies, environmental NGOs, and government agencies, are now far more likely to publicly acknowledge the importance of issues beyond their core

business, such as poverty alleviation, biodiversity conservation, and sustainable supply chains (Hahn and Kühnen, 2013). Yet gender equity and the urgent need to address climate change through greenhouse gas emission reductions are still rarely identified as core organizational concerns (Garnet et al., 2012). It is therefore important to understand not only the role sustainable businesses can play in achieving the SDGs, but how "green competition" and new business activities can stimulate innovation and be recognized as a source of future competitive advantage (Amit and Zott, 2012; Hajer et al., 2015; Rahdari et al., 2016). Progress toward sustainability management, and the achievement of the SDGs can be measured with specific indicators across diverse sectors, and thus public and private organizations have global sustainability benchmarks such as the Global Reporting Initiative (GRI), ISO 14001, the Carbon Disclosure Project (CDP) (see Siew, 2015 for larger list and review) that can be applied to evaluate their activities, strategies, and business outcomes. The example of firms such as Interface, Inc. – on track to reduce carbon emissions, waste, water and fossil fuel use to zero across its supply chains by 2020, with significant sales increases – has demonstrated that sustainable corporate behaviors can not only allow for profits and growth, but also drive them (Anderson and White, 2014; Hoffman et al., 2014).

Commercial landscapes are now different than in the past, with resource constraints, emerging markets, unprecedented rates of change in technology, and novel business models creating disruptions for traditional strategic management paradigms. The commercial parameters of 21st century business are more dynamic, distributed, transparent, and global than ever before (Guillén and Baeza, 2012; Palmer and Flanagan, 2016). These factors – the external pressures of social licence to operate and regulation, internal changes to corporate cultures, and the challenges and opportunities of digitalized global markets – mean that business requires new models of strategic management to survive and succeed, necessitating a realistic and genuine reflection on traditional business thinking and assumptions about the future (Hart and Dowell, 2011). However, it is not always apparent how sustainability behaviors offer advantages for business, highlighting the need for new analytical frameworks and tools (Hoffman et al., 2014). The principles of industrial ecology can facilitate the integration of sustainability into business practice, and have the potential to provide the breakthrough tools and methodologies that support and deliver sustainable business activity (Hoffman et al., 2014; Korhonen, 2004; 2005). This paper explores the overlaps between industrial ecology principles and strategic management theory, and investigates how these synergies might allow businesses to contribute to the achievement of the SDGs. Ongoing quantitative research into the financial benefits of industrial ecology in delivering strategic sustainability outcomes for business will further assist in highlighting the value of IE concepts and methodologies (Hoffman et al., 2014; Williams et al., 2017).

The paper proceeds as follows. In section 2, we present a brief review of literature that examines the relationships between business and sustainable development, with a focus on industrial ecology and its role in facilitating business activity in line with sustainable development. In section 3 we provide detailed explanations of the methods applied in the study, including the text-mining analysis conducted with Leximancer™ software. Section 3 presents results, and in section 4 we discuss the findings and implications of the analysis. Section 5 concludes the paper, highlighting important next steps for the integration of IE concepts within strategic management theory.

2. Business, sustainable development, and industrial ecology

Business and the private sector have a critical role to play in achieving the SDGs. Governments of both developed and newly developing countries do not have the finances, resources, and indeed capabilities to provide all the solutions necessary to achieve the SDGs. The private sector will need to play a central part in sustainable development, not only in terms of economic growth, but also in terms of the environmental and social needs of the 21st century. Firms have traditionally viewed sustainability policies as necessarily

subordinate to financial and operational priorities. Since Friedman's (1970) declaration that the sole social responsibility of firms is to provide a return to shareholders, rather than benefit to the wider community, sustainability has been considered an unnecessary cost, external to the primary role of the business (Porter and Kramer, 2011; Westley et al., 2011). Negative environmental impacts have been seen as an inevitable result of resource and product development. This perspective is apparent in early strategic management literature, where social and environmental sustainability principles are not explicitly considered, instead focussing on internal capabilities and external market dynamics for the competitive advantage of a firm (e.g. Porter 1979, Wernerfelt, Teece, Pisano & Shuen 1997). A turning point in the discussion of business activity and sustainable development came with Stuart Hart's "Natural-Resources-Based View of the Firm" (Hart and Dowell, 2011). Hart posited that strategists and organisational theorists must begin to grasp how environmentally oriented resources and capabilities can yield sustainable sources of competitive advantage – a paradigm shift from conventional management thinking (Gladwin et al., 1995). This resulted in a reframing of Wernerfelt's resources-based view of the firm (RBV) to A Natural-Resources-Based View of the Firm (NRBV) (Hart, 1995). The NRBV identified strategic advantages for organisations that derived from their relationships with the natural environment. Hart's seminal contribution was to identify competitive advantage not based solely on efficiency of resource input and product output supply chains, but as a paradigmatic shift to understanding commercial enterprises in terms of how their relationships with the natural environment in which they exist are sustained, and from which they derive productive value (Hart and Dowell, 2011). The NRBV therefore expanded the conceptual boundaries of firms' accounting, and encouraged business managers to recognise the reality of the organisation as part of an interrelated human-environment system – the beginnings of a systems thinking approach to business.

Research into the positioning of business as part of an interrelated human-nature system has continued since Hart's NRBV (e.g. González-Benito & González-Benito, 2005; Hart et al., 2011). In a recent review of systems thinking and sustainability management literature, Williams et al. (2017) identified eight dominant themes that emerge, one of which was IE. This echoes calls from other authors (e.g. Hoffman et al., 2014; Korhonen, 2005; 2004) for further integration of IE thinking and principles into management literature (and vice versa) to encourage business activity that promotes sustainable development. While IE includes tools, methods and principles that are relevant to business management, there is limited research that explicitly explores the relationship between IE and a broader agenda of business strategy for sustainable development. For example, Ayres and Ayres (2002) suggested that industrial ecology (IE) focuses on product design and manufacturing processes and views firms (businesses) as agents for environmental (as well as economic) improvement. They linked IE with questions of carrying capacity and ecological resilience, asking to what extent is technological society perturbing or undermining the ecosystems that provide critical services to humanity. They also alluded to a broader definition of IE given by Robert White, the former President of the US National Academy of Engineering. White (1994, p. v) defined IE as "the study of the flows of materials and energy in industrial and consumer activities, of the efffects of these flows on the environment and of the influences of economic, political, regulatory, and social factors on the flow, use and transformation of resources."

Through the integration of more holistic approaches to IE and complexity science, the field can be expanded from a set of tools used to understand material and energy flows, to an interdisciplinary field that can help managers make decisions and address complex sustainability challenges (DeLaurentis and Ayyalasomayajula, 2009; Williams et al., 2017). Korhonen et al. (2004), in an editorial in *Business Strategy and Environment* suggested that aspects of industrial ecology (IE) can be effectively linked to business management and policy studies. Like many authors on industrial ecology (Frosch and Gallopolous, 1989; Graedel and Allenby, 1995; Ayres and Ayres, 2002; Rosano and Schianetz, 2014), Korhonen et al. suggest that IE and its focus on 'industrial ecosystems' as models of sustainable industrial activity, can be used as a metaphor for sustainable

production to provide innovative routes to change present unsustainable industrial and business systems. They suggested three particular themes in which IE can link with management areas. First, the use of IE systems thinking and network philosophy (which could assist in improving inter-organizational management to develop a more holistic biological systems approach to environmental management, and closed loop and circular production systems). Second, the use of IE material flow studies of matter and energy (which encourage a focus on the management of (scarce) resources, energy, water, and waste). Third, IE is often used as a source of inspiration and creativity in the transformation of management and strategic visions towards a new sustainability culture (Korhonen et al., 2004). An important question is therefore whether IE principles can complement strategic business priorities and provide business competitive advantage and simultaneous by contribution to the SDGs as common international goals for sustainable development? (Hoffman et al., 2014).

In this paper, we explore this question, examining the relationship between the principles of IE as described by Ayres and Ayres (2002) – dematerialization and eco-efficiency, corporate stewardship, technological innovation, biological analogies, systems thinking, and forward looking research and practice – and traditional strategic management principles – efficiency, innovation, corporate citizenship, strategic intelligence, competitive advantage, and value maximization (Atkeson and Burstein, 2010; Korhonen, 2004; Sharma, 2000), and investigate how these can contribute to the achievement of the SDGs. In other words, the aim of this research is to establish the potential crossover between IE, business strategy, and the SDGs and identify specific ways business efforts can contribute to sustainability outcomes. The central research question in this paper is therefore "How can the key concepts of industrial ecology and strategic management promote sustainable development in line with the SDGs?" This study identifies the overlaps between industrial ecology principles and strategic management theory, and investigates current ways in which these synergies might allow businesses to contribute to the achievement of the SDGs.

3. Methods

This study was designed as a scoping study on the crossovers and connectivity between industrial ecology, business strategy, and the SDGs. A scoping study methodology was chosen to identify existing synergies and establish foundations for further research. While there are diverse methodological approaches for scoping studies (Arksey and O'Malley, 2005; Sarrami-Foroushani et al., 2015), we sought to integrate a rigorous and transparent literature review with quantitative analysis to synthesize this area of interdisciplinary research and identify research crossovers between different areas of relevant literature – industrial ecology, strategic business management, and sustainable development (Arksey and O'Malley, 2005; Pickering and Byrne, 2014).

The methodology involved three steps: a systematic, quantitative literature review reviewing online databases using selected research criteria; a software-driven text mining analysis of the SDGs; and an integrated analysis of the literature data set (step 1) using concepts derived from the SDG texts (step 2). The second and third steps in the study involved use of a text mining software tool called Leximancer^{TM}. The study was not intended to explore specific examples of how IE principles had resulted in quantifiable competitive advantage, but identified the conceptual crossovers between IE and strategic management, and how these are relevant to the potential achievement of SDGs by firms.

Leximancer software is useful in exploring concepts across large data sets (Chen and Bouvain, 2009; Smith and Humphreys, 2006). It analyses text using thesaurus-derived concepts from the document sets, iteratively building up a thesaurus of associated concepts through intelligent proprietary algorithms. Concepts are indexed and weighted, resulting in a thematic view of relationships between concepts, which can subsequently be mapped in two dimensions allowing for themes specific to the research problem to be investigated

(Thomas, 2014). In other words, Leximancer reads document sets and produces a map of key concepts, with their relationships indicated by their proximity or distance on the map. Leximancer has been used in a diverse range of applications, including in the examination of corporate social responsibility reporting (Chen and Bouvain, 2009), historical trends in long range planning literature (Cummings and Daellenbach, 2009) and the roles of finance and commerce in climate change mitigation markets (Thomas, 2014). Concepts are placed on the map in proximity to terms with which they share meaning or a relationship. Through examination of the resulting concept map, frequency counts, and relationships between both concepts and themes, qualitative interpretations can be made based on the quantitative, algorithmic analysis (Smith and Humphreys, 2006). Leximancer identifies the main concepts present in document sets, and indicates how these concepts are thematically connected.

The first step of the study involved assembling a data set of relevant literature that discussed all three topic areas, using the systematic quantitative literature review process outlined by Pickering and Byrne (2014). The search was conducted in the leading databases relevant to business, technology, and sustainability, namely ProQuest ABI/INFORM, comprising ABI/INFORM Global, ABI/INFORM Trade and Industry, and ABI/INFORM Dateline. The database covers peer-reviewed journals, theses and dissertations, working papers, industry reports, leading business and economics periodicals, and major news media sources. The database seeks to represent and provide a complete picture of international business and corporate trends (see http://www.proquest.com/products-services/abi_inform_complete.html). Other databases (including Scopus and Web of Science) were tested, but resulted in few relevant hits for all three search terms, and were eventually excluded from the final analysis.

The search terms chosen were “industrial ecology”, “business strategy” and “sustainable development”, and the database search captured papers in which all three search terms appeared. Initially the search terms were entered without quotation marks, but this resulted in over 4000 results. Quotation marks were added to each search phrase, which reduced the search results by a factor of 10 and targeted the results towards the specific topics of interest in this study – the examination of the crossover between IE, business strategy, and the SDGs. The analysis was completed progressively over a number of weeks but finalised on 31 July 2015. Results were filtered to include only peer-reviewed, scholarly articles, published in English, for which full-text papers were available. This resulted in a data set of 290 unique papers and associated citation information. Microsoft Excel software was used to determine metrics from the citation information, including counts for journal title, source database, place of publication, and subject tags, inter alia (see Supplementary Materials for the full data set). Papers were read to ensure their relevance and confirm that each considered all three specific topics of interest in this study: “industrial ecology”, “business strategy” and “sustainable development”.

The second step in the research applied the Leximancer software to identify the main concepts present in the SDGs. The full text of the 17 goals and the associated 169 target descriptions was entered into the Leximancer software, and a number of iterations run to develop a stable concept map. Words improperly identified as concepts (e.g. ‘including’, ‘use’) were manually removed from the analysis for clarity. The results of this step provided ‘seed’ concepts that characterize the SDGs – these are shown in Table 1.

The third step involved a dual process, also using Leximancer, to analyze the data set of literature using the seed concepts identified in the SDG full text. Concepts were again manually vetted to remove duplicates resulting from the dual data sets, group similar terms (e.g. environment and environmental, companies and firms, etc.), remove improperly identified terms, and to ensure a stable set of results. This produced a detailed and extensive analysis of the literature data set indicating how and to what extent it incorporated the central concepts found in the SDGs. These results are shown in Table S1. In addition, up to three keywords were manually identified for each of the 17 SDGs, based on the authors’ reading of the text. For example, the text

for SDG2 reads “End hunger, achieve food security and improved nutrition, and promote sustainable agriculture”, from which the keywords ‘nutrition’, ‘food’, and ‘agriculture’ were identified as being principal literature descriptors of the goal. These keywords were subsequently entered into the Leximancer software as concept seeds in place of the automatically generated concepts used previously. The project was run again and vetted as in the previous phases, with concept maps and frequency counts produced (these are shown in Table 2 and Figure 2). These were then used to quantify areas where the literature on IE and business strategy overlap to support the implementation of the SDGs.

In summary, the analysis identified literature discussing conceptual crossovers and synergies between industrial ecology and strategic management, and tested this body of work using the key concepts present in the text of the SDGs. The results indicated specific areas in which businesses can apply IE principles and achieve competitive advantage while addressing the sustainability aspirations of the SDGs.

A schematic of the research method is presented in Figure 1.

Figure 1 about here

4. Results

The first step in the study was the systematic literature review, with a total of 290 academic articles mentioning all three search terms identified through the search. The data set (attached as Supplementary Information) includes a variety of field codes or ‘tags’ for each article, and comprised: 230 ‘feature’ articles (meaning papers appearing in special issues or otherwise highlighted as a ‘feature article’ in the database field codes), 18 articles from sources labelled as periodicals, 11 regular journal articles, with the remainder consisting of case studies, literature reviews, and book reviews, inter alia. All the papers identified were found in the ProQuest/ABI INFORM Global database. A small number of papers were identified in the Scopus and Web of Science databases, but were excluded from the assessment for not meeting the selection criteria (i.e. peer-reviewed journal article, for which full text was available). Articles were published in 117 unique journals. The major journals publishing in this field are *Business Strategy and the Environment* (29), *Journal of Business Ethics* (26), *Supply Chain Management* (13), *International Journal of Operations and Production Management* (11), and *Greener Management International* (9). Publications per year generally followed an upward trend, with only a single paper identified in 1994, while 38 unique papers were published in 2012. Numbers have decreased slightly since this time, with 34 published in 2013, 28 in 2014 and 6 identified in 2015. From the citation information, 520 unique subject tags were identified, with the most common being Studies (197), Sustainable Development (93), Environmental Management (93), Social Responsibility (49), and Supply Chains (36). The ‘Studies’ resulted can be discounted, representing the large proportion of papers reporting original research.

In the second step of the study, a digital copy of the proposed SDGs and associated targets was loaded into the Leximancer software. The resulting concept map is presented in Figure 2, with associated concept frequency and relevance counts displayed in Table 1.

Table 1 about here

Figure 2 about here

Major themes that emerge from the Leximancer analysis of the SDGs are ‘countries’, ‘sustainable’, and ‘development’, which is unsurprising considering the context for which they were written. However, when

these concepts are examined in greater detail, relationships that imply the role of business begin to emerge. For example, the concept ‘sustainable’ is strongly associated with ‘innovation’, ‘employment’, ‘technological’ while the term ‘development’ is associated with ‘knowledge’, ‘account’, and ‘partnership’, terms that have relevance for business as well as in governance.

Apart from the obvious terms of ‘sustainable’ and ‘development’, the major themes that emerge from the SDG analysis are ‘countries’, ‘international’, ‘national’, and ‘developing’. Closer examination of these concepts shows the text discusses ‘countries’ and ‘national’ in similar contexts, mainly related to least developed nations and provision of the capacity and support necessary for their development. ‘International’ however appears to be related more to partnerships, capacity building, and investment between nations. This is repeated with ‘domestic’ being strongly associated with terms including ‘partnership’, ‘industrial’, ‘diversification’ and ‘leadership’,

In the stable concept map (Figure 2), ‘implementation’ is always positioned on the outside, with few linkages, indicating that the SDG text does not discuss this idea to any great extent. Two major groupings of concepts also appear consistently throughout the analysis and can therefore be considered closely related. These are related to sustainable use of ecosystems and resources (‘food’, ‘land’, ‘resources’, ‘sustainably’, ‘ecosystems’, and ‘strategies’) and access to needs for vulnerable persons (‘vulnerable’, ‘persons’, ‘women’, ‘access’ and ‘needs’).

In the third step of the study, seeding the Leximancer analysis of the data set with the key concepts extracted from the SDGs, it was possible to identify strengths and weaknesses in using IE as a strategic tool for business to promote the SDGs. Of the 28 concepts identified as key in the SDG analysis (Table 1), all 28 were directly identified by the Leximancer algorithms as having some degree of relevance in literature data set (Table S1). This relevance varied from ‘development’ with 37% and 4778 mentions in the data set of papers, to ‘disasters’ that received only 95 mentions and a relevance score of 1%. The fact that all concepts identified from the SDGs appeared in the IE data set is indicative of the crossover between the SDGs and the principles and ideas that underlie IE principles. The concepts identified in SDG analysis (Table 1) are shown in the main literature data set (Table S1), and along with their frequency counts and relevance scores (relevance within the literature data set) are highlighted in bold.

The literature represented in the data set focuses on key themes that include business, management, performance, and their interaction with sustainability, along with social and environmental factors. Business is the predominant concept identified through the analysis, and it maintains strong connections with the other key themes, indicating that the literature identifies connections between business performance, management, and social and environmental aspects of sustainability. The text suggests a positive relationship between business management and economic performance through environmentally conscious activity. Additionally, thematic groupings and relationships appear through examination of the concept map (Figure 3). Business concepts are grouped (‘market’, ‘performance’, ‘value’, ‘strategy’), as are terms reminiscent of corporate triple bottom line (‘social’, ‘environmental’, ‘economic’), governance (‘policy’, ‘global’, ‘developing’), and research (‘framework’, ‘literature’, ‘theory’, ‘knowledge’). Full results including frequency counts and relevance are presented in Table S1 in the Supplementary Information, with the associated concept map shown as Figure 3.

Figure 3 about here

The second part of the third step was a keyword analysis of the literature data set using up to three terms taken from the headline text of each of the 17 SDGs. This was completed to determine strengths and weaknesses in

promotion of individual SDGs (in the literature data set), with the results presented in Table 2. All keywords identified were present in the data set, indicating a broad correlation between IE principles and the SDG texts. The strongest relevance was seen in Goals 7 (Affordable and Clean Energy), 9 (Industry, Innovation and Infrastructure), 12 (Responsible Consumption and Production), and 13 (Climate Action) – these results are highlighted in bold in Table 2. These are areas in which IE principles are apparent, namely energy efficiency, impact reduction, closing the production-consumption cycle, and innovation. The analysis also reveals gaps, where IE plays a minimal role. These are marine environments (Goal 14), terrestrial environments (Goal 15), promotion of gender equality (Goal 5), and sustainable human settlements (Goal 11). While the keywords identified for these goals do not appear in great numbers in the text, the ideas that underlie these goals are important components in IE. For instance, the conservation, protection, and sustainable use of natural resources in marine environments and terrestrial ecosystems are a major component of sustainable production-consumption thinking which is a key tenet of IE.

Table 2 about here

5. Discussion

The combined analysis – integrating results of the second and third steps in the study – identified three broad areas where industrial ecology principles can lead to a sustainable competitive advantage for business: resource efficiency, innovation, and climate change mitigation and adaptation.

First, the efficient use of energy and resources are areas where business can achieve a competitive advantage in line with the sustainability goals (Bocken et al. 2015). By reducing the reliance of business on finite resources, the exposure of the business to changing markets is minimized, while reducing the impact of the business itself. As an example, one of the major tools in practical IE implementation is a mass and energy balance on the system being examined (Korhonen 2004). While this tool is commonly used in engineering practice, it also has implications for identifying waste and inefficiencies in the system and driving continuous improvement. These are ideas that can also be applied in traditional business strategy literature and practice and are synonymous with reduced operating costs and minimizing exposure of the firm to volatility in markets and supply constraints. Resource efficiency is arguably an obvious synergy between IE principles and business strategy and competitive advantage.

Second, the pursuit of innovation as a source of competitive advantage is a major element in the existing strategic management literature. This analysis indicates that innovation in the pursuit of sustainability outcomes can also lead to a competitive advantage for business, through the opening of new markets, products, and business models. The recognition by executives that new business models offer greater strategic value than new products or services (Amit and Zott 2012; Baldassarre et al. 2017) is a critical baseline for commercial enterprises facing a rapidly changing economic landscape, with user-driven innovations such as design thinking, niche-oriented lean start-ups, and the distributed “gig” economy of flexible, highly skilled contractors all challenging traditional expectations of business behaviors and financial processes (Baldassarre et al., 2017; Friedmann, 2014). The application of IE principles to strategic thinking allows executives to engage more easily with the changing nature of modern markets (Etsy and Porter, 1998).

Finally, using industrial ecology principles can play a role in the mitigation of the impacts of business activities on climate change, and firms’ adaptation to those impacts. These two areas – mitigation and adaptation – relate directly to traditional management concepts of internal and external capabilities and environments (Wernerfelt 1984).

Mitigation can refer to reducing environmental impacts including water use and release of toxins into the environment, but is commonly used to describe a firm's capacity to reduce its carbon liabilities in the form of direct greenhouse gas emissions (e.g. methane escaping from open cut mines or gas wells, or carbon dioxide produced through burning of fossil fuels in fleets or power plants) or indirect emissions (through electricity used in factories and offices, or other business activities such as airline travel). The carbon footprint of businesses is increasingly a factor in financial compliance obligations, as countries implement carbon pricing legislation in various forms to meet their commitments under international agreements, particularly the United Nations Framework Convention on Climate Change. 41 countries including all OECD countries and Argentina, Brazil, China, India, Indonesia, Russia and South Africa have effective carbon pricing in place (OECD, 2016), and while this is deemed inadequate to meet agreed international mitigation targets (Le Quéré et al., 2015), regulatory constraints on businesses continue to grow. Previous research suggests that harnessing carbon market frameworks is a powerful means to develop new industries and achieve national strategic economic goals (Thomas et al., 2011).

Adaptation relates to an organization's capacity to maintain its activities and financial viability in the context of changing external conditions, which can be long-term market fluctuations, social pressures, or legislative mandates, or abrupt, episodic impacts, such as extreme weather events or natural disasters, which can damage supply chains or assets (Linnenluecke and Griffiths, 2011).

The business logics of carbon mitigation for firms are clear: operational improvement, anticipation of climate change regulations, access to new sources of capital, better risk management, improved corporate reputation, new market opportunities, and enhanced stakeholder engagement (Hoffman 2005). This study has demonstrated the utility of IE principles in facilitating these outcomes. As the impacts of climate change increase in the future, the competitive advantages associated with incorporating these principles and methods into the strategic thinking of businesses will only increase. IE has the potential to bring relevant benefits for businesses if it is effectively embedded in corporate decision-making processes.

In the past it has been difficult to define sustainable development in a business context, resulting in the limited rollout and effectiveness of actions required to shift commercial behaviors towards proactive sustainability. Activities have either been focused on pollution prevention, product stewardship, or corporate social responsibility (Hart and Dowell, 2011). The positioning of the firm on the sustainability spectrum (Seager, 2008) has been crucial in the effectiveness of these activities, as corporate culture is a major driver of not only overall strategy, but the implementation of sustainability initiatives. Unfortunately, given the current rapid and significant conditions of global change (in environmental, climatic, economic, atechnological, and social areas), meeting the minimum standard is no longer enough, and societal, market, and regulatory drivers are forcing companies to operate in a more socially and environmentally responsible fashion. While there is a distinct lack of integration of these ideas and subsequent paucity of scientific literature (Hoffman et al., 2014), there is a movement in some firms and business sectors to focus on integrating sustainability into operations and strategy. The literature data set collated in this study comprises studies that apply the principles of IE to gain competitive advantage in business activities consistent with the notion of sustainable development captured in the SDGs.

IE focuses on six key areas that have the potential to provide businesses with a competitive advantage: dematerialization and eco-efficiency, a strategic orientation considering the future in both production and consumption realms, a redefinition of the role of business, the use of technological innovation to solve problems and create market positioning, systems thinking, and the application of a biological analogy in which industrial systems are reimagined as complex industrial ecosystems existing in symbiosis with larger social and biophysical environments (Ayres and Ayres 2002). Integration of these IE concepts into traditional

models of business practice and long-term strategic management can lead to business activities consistent with the notion of shared value discussed by Porter and Kramer (2011), and support meaningful progress towards realization of the SDGs. Other frameworks have been proposed that aim to capture environmentally and socially proactive business activity, including the Creating Sustainable Value framework (Hart et al., 2003) and Eco-Synergy approach (OSU Centre for Resilience, n.d.). These frameworks share similarities with IE principles (e.g. systems thinking, efficient use of resources), but their inclusion in this analysis is beyond the scope of this study, so it is not entirely clear if and how these frameworks directly support the enactment of the SDGs.

At their core, the SDGs are a set of measurable and accountable targets designed to guide the development, policy, and priorities of UN member states in promoting sustainable development (cf. GBD 2015 SDG Collaborators 2016; Malik et al. 2015; and see SDSN 2015). Transfer of these goals and targets from the international scale that is the UN, to the national scale of individual governments, to the highly varied context that is business is where the difficulty lies. While the SDGs appear to focus on the role of government, the concepts that make up the goals and target have a close relationship with the role of business, and the realization of specific SDG targets and objectives relies on national policy settings and initiatives that constrain or incentivize actions by non-government and private sector organizations. Traditional business approaches have pursued economic activity, often at the expense of the environment and society that are fundamental to their operation. As discussed in this paper, social and environmental factors form a major part of not only the SDGs, but a wider discussion of sustainability. Subsequently, traditional business strategy may be at odds with the aims of the SDGs. The evolution of the role of business suggests that corporate philosophies and commercial activities can no longer be focused solely on economic factors, but are also inexorably linked to social and environmental drivers (Westley et al. 2011).

5.1 Limitations

It is important to acknowledge the limitations of this research. Firstly, the criteria used to collate the data set in the systematic literature review process could be criticized for failing to capture all the literature at the interface of IE, strategic management, and sustainable development. This is a valid criticism as the data set was reduced by a factor of 10 with the introduction of quotation marks to the initial search keywords. Although this reduced the number of search results and size of the data set, it also had the effect of tightening the scope of the literature data set to those papers that were directly relevant to the research question at the heart of this paper. We consider that this was a necessary measure, as the smaller data set was more manageable and compatible with the tools and analysis techniques used while also capturing the most relevant sample of literature. Further, as the analysis was based on text mining and subsequent thematic analysis, it may be that the work has not fully captured all important nuances within the individual literature. This is an important limitation to note in this analysis. However, the aim of this study was to provide a scoping study identifying synergies and thematic crossovers between the three research topics, and their potential similarities in both definition and meaning in exploring the research question – “How can the key concepts of industrial ecology and strategic management promote sustainable development in line with the SDGs?” Preliminary exploration of the broad crossover between these distinct but converging areas of research identified a number of areas in which the principles of IE and business strategy can be applied by businesses to pursue sustainability outcomes. However, a more detailed and extensive qualitative analysis of the field should be conducted to verify and further explore the findings of this research. Finally, it should be noted that the papers identified in this study generally had a definition of success and value for organizations that is consistent with the traditional management literature (e.g. economic value for stakeholders). The discussion of sustainable development is complex, and it is difficult to fully capture the value of social and environmentally focused actions of organizations in a broad analysis such as this. Alternate metrics of success and value (e.g. social-ecological resilience, social licence to operate, and ecosystem services) are also important aspects of both IE

and sustainable development (as is evident through the 17 goals and 169 targets that constitute the SDGs), and should be incorporated into future definitions of organizational sustainability strategy.

6. Conclusion

The traditional business practices fundamental to 20th century economic development have largely ignored the natural environment and society in which they have operated. As we move further into the 21st century – a period in which human activities are the primary drivers of planetary environmental and climate dynamics (Waters et al., 2016) – it is evident that business leaders cannot operate in isolation, but must alter their view of the firm to one in which they recognize their critical role in a larger social-ecological-industrial system. A shift in strategic direction for business is required, one that identifies the competitive advantages associated with environmentally and socially responsible business practices through the science of industrial ecology, its focus on sustainable industrial systems and its interconnection with modern business strategy. The analysis presented here contributes to the growing body of evidence that proactive sustainability practices are strategically advantageous for firms.

The broad central principles of IE have the potential to contribute to the achievement of the international SDGs. IE provides a basis for a further evolution in thinking where the firm exists as part of, and because of, the social-ecological system, and competitive advantage is found through the combination of internal competencies and from the full consideration of external drivers. This study suggests areas for further research, including detailed assessment of the value creation frameworks mentioned previously – the Creating Sustainable Value framework (Hart et al., 2003) and Eco-Synergy approach (OSU Centre for Resilience, n.d.), inter alia – to determine synergies between these and IE. Even more importantly, the next step in this evolution in sustainable business thinking will be to develop the methods and frameworks to enable the transfer and sharing of ideas between IE and strategic management. This should be a two-way transfer as no single discipline or strategy can solve the sustainability challenge alone. There is clearly a need for conceptual frameworks that can be applied by business managers to harness IE principles and concepts in strategic planning and evaluation processes. This area warrants further research and there is need for the development and articulation of theoretical frameworks that integrate IE principles and strategic management concepts in a way that offers practical operational tools for business managers. Additionally, development of quantitative studies that analyse the benefits of implementing IE principles and approaches in corporate decision-making to reach the SDGs should be conducted, using the results of this paper as baseline.

The private sector is critical to achieving the SDGs. Business plays a central role in the provision of the products and services that are required now and into the future, and is the cornerstone for economic investment, job creation, and a multitude of other important aspects of sustainable development. It is now necessary to embrace a more holistic approach to economic development, building value in human and natural systems for the long term. The concepts that underlie IE align closely with the ideas of sustainable development that inform the SDGs. This paper has identified some of the potential crossovers in IE principles in the strategic pursuit of competitive business advantage and the SDGs. While IE at the firm (business) level can be seen as a useful tool for improving resorce productivity, it is not an independent guide to competitive strategy (Etsy and Porter 1998). This research identified three particular areas of crossover and connectivity in the industrial ecology, business strategy, and sustainable development literatures: 1) the efficient use of energy and resources; 2) the pursuit of innovation; and 3) mitigation of and adaptation to climate change, as areas of competitive advantage for firms resulting from application of IE principles. The identification and focus on competitive advantage through these sustainable management and development activities, should be encouraged, promoting the potential realization of the SDGs and the ongoing evolution of current business thinking to meet the sustainability challenges ahead.

Captions

Figure 1: Schematic of the research process
Figure 2: Concept map derived from Leximancer analysis of UN Sustainable Development Goals.
Figure 3: Thematic map derived from Leximancer analysis of literature data set using SDG analysis results as seed concepts.

Table 1: Results from the Leximancer analysis of the UN Sustainable Development Goals.
Table 2: Results of analysis using manually identified keywords for each SDG as seed concepts.

Supplementary Information:
Table S1: Results from Leximancer analysis of literature data set using SDG analysis results as seed concepts. Data set of articles included in systematic quantitative assessment.

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Tables

Table 1: Results from the Leximancer analysis of the UN Sustainable Development Goals.

Concept	Count	Relevance (%)
countries	75	100
sustainable	57	76
development	56	75
developing	53	71
access	48	64
international	46	61
national	41	55
support	30	40
resources	28	37
promote	24	32
technology	24	32
domestic	22	29
increase	22	29
women	20	27

Concept	Count	Relevance (%)
universal	18	24
persons	18	24
land	18	24
strategies	14	19
regional	14	19
sustainably	14	19
vulnerable	13	17
implementation	13	17
innovation	11	15
ecosystems	11	15
disasters	11	15
gender	10	13
needs	9	12
food	6	8

Table 2: Results of analysis using manually identified keywords for each SDG as seed concepts.

SDG	Keyword	Concept Count	Relevance (%)
Goal 1	poverty	181	5
Goal 2	nutrition	188	5
	agriculture	297	9
	food	756	22
Goal 3	health	698	20
	wellbeing	92	3
Goal 4	education	810	23
	learning	812	23
	inclusive	558	16
Goal 5	gender	135	4
	equality	128	4
Goal 6	water	964	28
	sanitation	720	21
Goal 7	**energy**	**2950**	**85**
	modern	287	8
Goal 8	employment	249	7
	economic growth	297	9
Goal 9	**innovation**	**2080**	**60**
	infrastructure	467	13

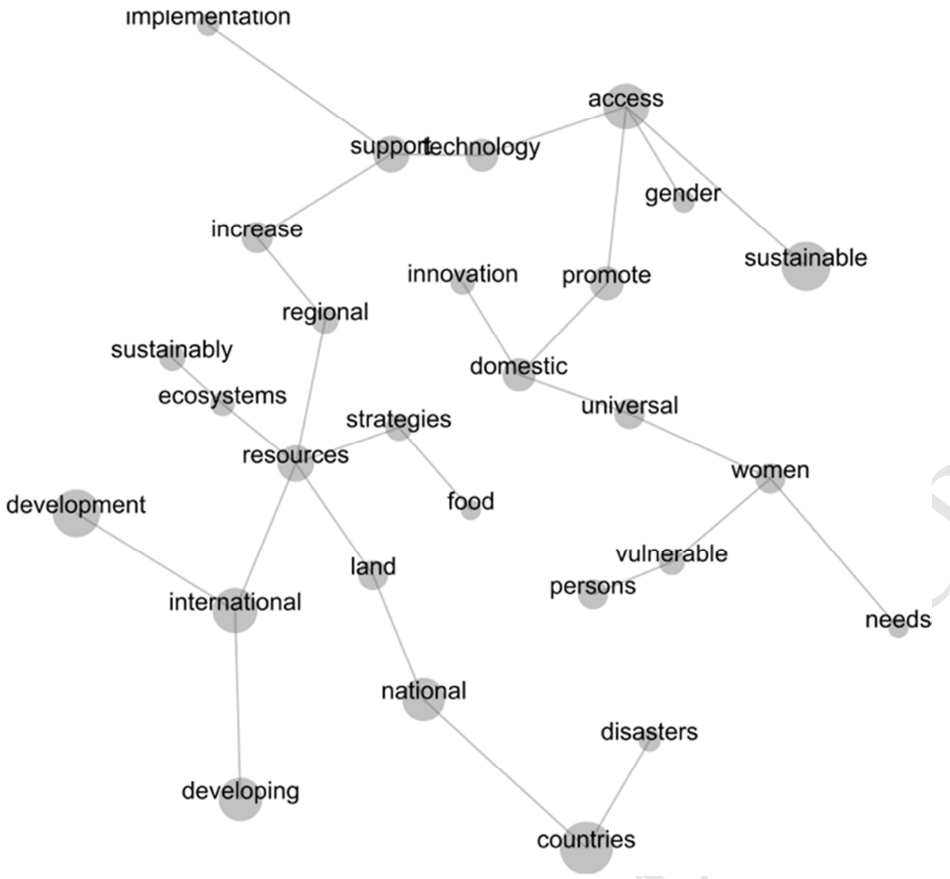
SDG	Keyword	Concept Count	Relevance (%)
Goal 10	inequality	35	1
	equity	481	14
Goal 11	cities	214	6
	settlement	25	1
Goal 12	**production**	**2464**	**71**
	consumption	**1591**	**46**
Goal 13	**climate change**	**974**	**28**
	impact	**2341**	**67**
Goal 14	ocean	55	2
	sea	37	1
	marine	41	1
Goal 15	ecosystem	767	22
	forest	221	6
	degradation	280	8
Goal 16	society	1206	35
	justice	251	7
	accountable	305	9
Goal 17	implement	785	23
	partnership	311	9

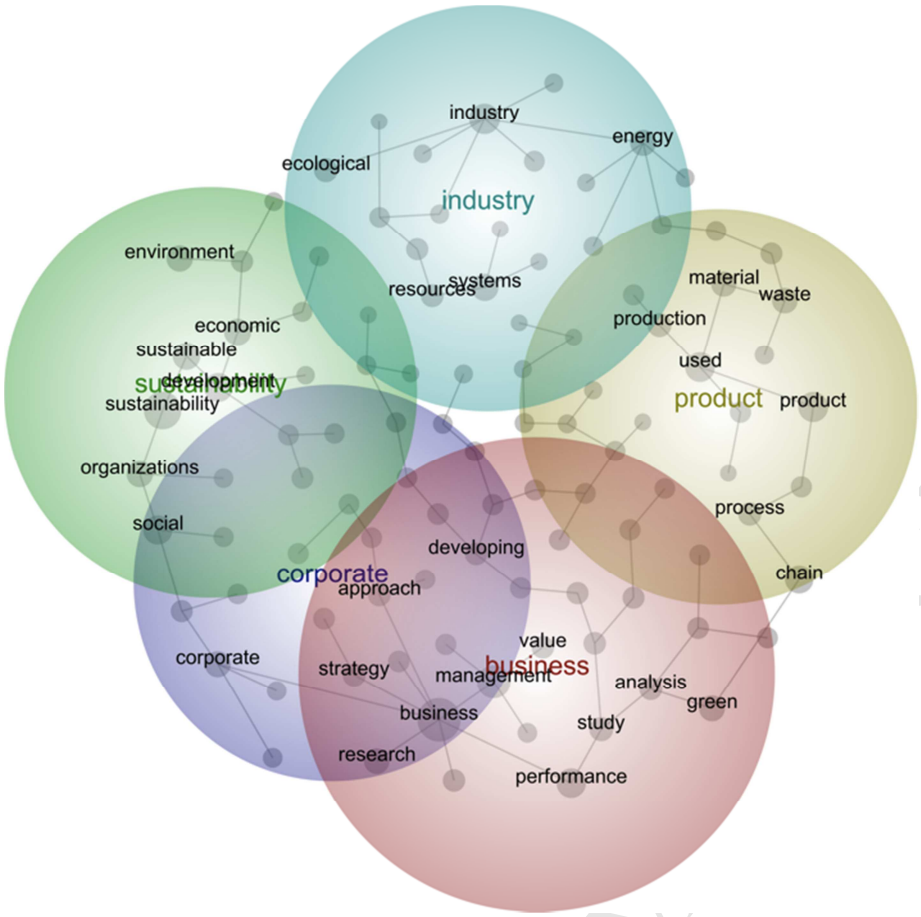
Table S1: Result from Leximancer analysis of literature database using SDG analysis results as seed concepts.

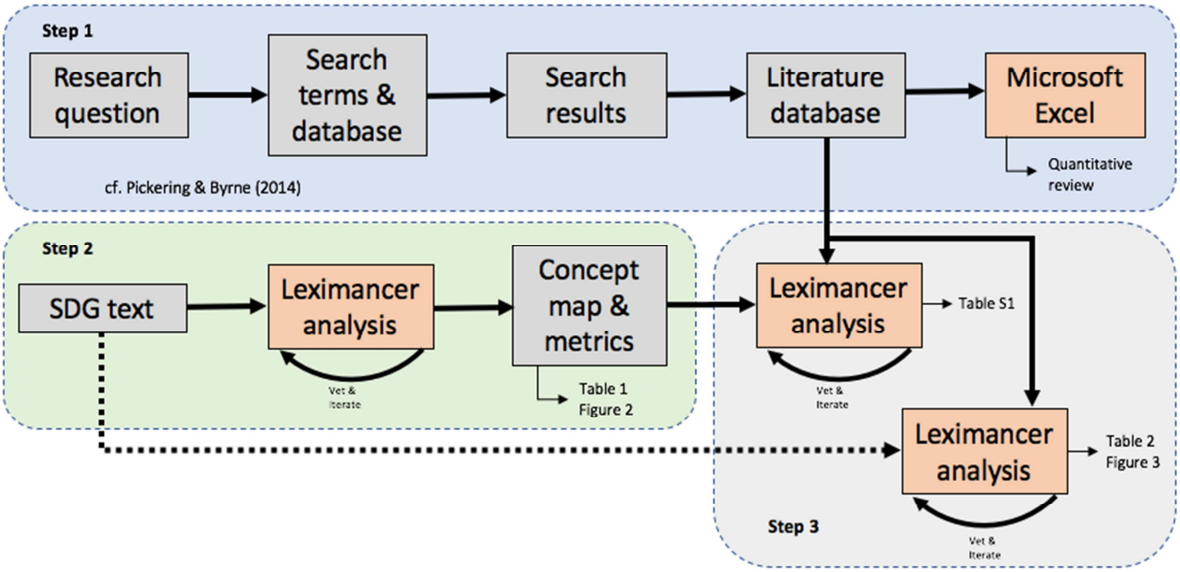
Concept	Count	Relevance (%)
business	13080	100
sustainability	8834	68
management	7696	59
performance	6540	50
chain	6096	47
industry	6072	46
product	5491	42
environment	5276	40
social	5223	40
used	5094	39
organizations	4814	37
development	**4778**	**37**
green	4596	35
systems	4192	32
economic	4186	32
corporate	4173	32
research	4101	31
sustainable	**3956**	**30**
study	3281	25
energy	3269	25
waste	3033	23
analysis	3006	23
material	2832	22
strategy	2766	21
process	2657	20
ecological	2617	20
value	2598	20
literature	2575	20
production	2525	19
case	2465	19
approach	2424	19
model	2355	18
market	2335	18
change	2302	18

Concept	Count	Relevance (%)
resources	**2283**	**17**
information	2256	17
responsibility	2186	17
policy	2177	17
strategies	**2163**	**17**
developing	**2154**	**16**
innovation	**2150**	**16**
data	2052	16
framework	2048	16
global	1892	14
paper	1879	14
studies	1865	14
role	1863	14
knowledge	1856	14
natural	1851	14
consumers	1832	14
manufacturing	1830	14
emissions	1821	14
pollution	1801	14
public	1777	14
support	**1743**	**13**
time	1731	13
reporting	1666	13
using	1665	13
consumption	1657	13
theory	1657	13
countries	**1600**	**12**
quality	1562	12
work	1560	12
life	1549	12
developed	1543	12
implementation	**1518**	**12**
accounting	1460	11
technology	**1422**	**11**

Concept	Count	Relevance (%)
local	1418	11
available	1401	11
needs	**1357**	**10**
government	1316	10
problems	1309	10
marketing	1289	10
nature	1281	10
values	1261	10
international	**1235**	**9**
human	1182	9
increase	**1180**	**9**
water	1137	9
oil	1133	9
power	1058	8
world	1037	8
carbon	937	7
people	884	7
least	826	6
regional	**802**	**6**
food	**778**	**6**
national	**743**	**6**
promote	**664**	**5**
domestic	**582**	**4**
ecosystems	**567**	**4**
access	**530**	**4**
land	**441**	**3**
universal	**304**	**2**
vulnerable	**252**	**2**
persons	**185**	**1**
gender	**175**	**1**
sustainably	**122**	**1**
women	**117**	**1**
disasters	**95**	**1**
interstices	79	1







Highlights

- Systematic review of literature with a thematic and conceptual analysis using Leximancer™.
- Industrial ecology principles are shown to lead to competitive advantage in line with Sustainable Development Goals.
- The study establishes a baseline for quantitative analysis of the strategic benefits of IE principles.