Sustainability strategy and blockchain-enabled life cycle assessment: a focus on materials industry

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Abstract
Sustainable development, especially with the 2030 Agenda for Sustainable Development and its Sustainable Development Goals (SDGs), has been a priority of corporations. Nevertheless, processes which are required to deliver both changes and impact to create a sustainable organization have been slow and challenging. The purpose of this research is first to explore the extent and nature of eco-sustainability policy and strategy implementation of Materials Industry Group (MIG) companies listed on the Australian Securities Exchange (ASX). The analysis shows that strategy is the core element for organizational sustainable development and strategy needs to be implemented at the enterprise-wide level and aligned with other dimensions within the McKinsey Seven S's (7S's) framework. The capabilities of life cycle assessment (LCA) that provides a holistic assessment of environmental impacts of products, from upstream and downstream perspectives, is under-explored. The case companies used in this research find it challenging to implement LCA. This research adds an additional dimension to the existing framework, suggesting the *possibilities* of adopting blockchain technology in strategizing sustainability strategy. Blockchain in the *systems* of the framework can be used in LCA to support sustainability and help organizations to achieve their targeted SDGs.

Keywords Sustainable development goals (SDGs) · Eco-sustainability · Blockchain · Life cycle assessment (LCA) · Corporate strategy · Sustainability

1 Introduction

Sustainable outcomes in business continues to challenge all forms of business in their attempts to get serious about creating impacts for sustainable development and achieve Sustainable Development Goals (SDGs). A recent survey of more than 1000 CEOs of the United Nations Global Compact (UNGC) member companies showed that 97% of CEOs believe that sustainability is essential to the future success of their business. They (87%) also believe that SDGs provide an opportunity to rethink approaches to sustainable value creation, and 78% already see opportunities to contribute through core business (Accenture 2018).

The World Meteorological Organization (2019) has stressed that CO_2 emissions have surged above the average recorded over the last decade. In the recent United Nations (UN) Sustainable Development Summit opening statement, Secretary-General said "we are far from where we need to be. We are off track". A more ambitious new sustainable development agenda and 141 SDG Acceleration Actions to accelerate progress were formally adopted at the summit in 2019 (as of this writing, the SDG Acceleration Actions has increased to 147).

Climate change, ongoing degradation of environmental sustainability and social systems have become a significant global business issue, as they can affect value creation (Husted et al. 2015), financial performance (Nakao et al. 2007),

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strategic positioning, market competitiveness, and long-term growth (Epstein 2008; Porter and Kramer 2006; Teh 2013). The effort to achieve sustainable development is redefining how business is run and how sustainability should be incorporated into business strategy (Bansal et al. 2016; Broman and Robèrt 2017). However, to make business sustainable remains a challenge for companies. For instance, one of the biggest challenges for companies is committing to sustainability and strategically planning for it (Sekera and Stimel 2011). McPhee (2014) provides a sustainable activity model to analyse firm's product-focused activities to further improve their decision-making process. Broman and Robèrt (2017) reflected on the 25-year learning process between scientists and practitioners and created a Framework for Strategic Sustainable Development helping organizations to thoroughly understand the context of global sustainability challenges.

Despite companies' efforts to minimize their negative environmental and social impacts, the process of creating a sustainable organization and achieving sustainable development has been slow (Baumgartner and Rauter 2017) and there is growing fatigue within senior management with the issue (França et al. 2017). This is due to an inability to make further advances in sustainability and embed sustainability throughout their organizations, relating to products and services, operations, processes, and ultimately decision-making (Bansal et al. 2016).

The intent of this paper is to investigate the structural parameters that impact how companies implement their eco-sustainability policy and strategy and to propose an additional dimension to that structure, suggesting the possibilities of adopting blockchain technology (blockchain) in strategizing sustainability strategy. The key research question addressed is How can blockchain technology address the challenges companies in Materials Industry Group face in implementing LCA, and facilitate a more effective implementation of LCA as part of their eco-sustainability policy and strategy? Specifically, this research seeks to provide a better understanding of how the use of blockchain in LCA can address the challenges associated with integrity, traceability and transparency of data and limitations inherent in LCA, given that many stakeholders can be involved in complex interdependent activities along the value chain. To answer this research question, this paper is structured in the following order: Sect. 2 presents the research background—sustainability and SDGs, and the Material Industry Group and McKinsey 7S's framework; Sect. 3 is the research method; Sect. 4 first analyses and discusses the interview findings. LCA was then introduced in Sect. 4.2, followed by the challenges to implement LCA; the proposed solution was then thoroughly discussed in 4.3. Finally, implications of the findings are discussed, alongside a consideration of limitations and future research in Sect. 5 and 6, respectively.

This research also answers the call made by the United Nations Economic Commission for Europe (2018) and World Economic Forum (WEF) (2018) focusing on adoption of blockchain as a strategy for transformation towards sustainable and resilient societies. This paper explores the extent and nature of eco-sustainability policy, the strategy of companies, then proposes and discusses the potential of adopting blockchain in three case companies in the Materials Industry Group (MIG) listed on the Australian Securities Exchange (ASX).

2 Research background

2.1 Sustainability and SDGs, and the Material Industry Group

The World Commission on Environment and Development, or Brundtland Commission's (1987, p. 43) definition of sustainability—"development that meets the needs of the present without compromising the ability of future generations to meet their own needs" has formed the premise of numerous initiatives for sustainable development. The concept of organizational sustainability is a subset of the larger concept of sustainability, which is intertwined with sustainable development (Jennings and Zandbergen 1995). It refers to enterprise's capability to generate wealth without compromising its environmental accountability and social stewardship (Baumgartner and Rauter 2017; Dyllick and Hockerts 2002). This is an idealistic but not practical proposition where new economics thinking, and models are required for a finite planet (Jackson 2009).

The 2030 Agenda for Sustainable Development and related 17 SDGs was launched and adopted at the UN General Assembly in September 2015 (UN 2015a). The Agenda and SDGs aim is to tackle the global economic, social and environmental challenges in all developed and developing countries (UN 2015b). This is the agreed blueprint to achieve a better and more sustainable future for all, by tackling global challenges, specifically, those related to poverty, inequality, climate, environmental degradation, prosperity, and peace and justice (Fig. 1). The Goals are interconnected and leave no one behind, hence, all 193 UN Member States have agreed to deliver these 17 SDGs and meet 169 targets by 2030 (UN 2015b).

The pursuit of sustainability creates avenue of opportunities for organizations to remain competitive (Bernal-Conesa et al. 2017; Epstein 2008). It challenges companies to rethink and innovate their business models (Clinton and

Fig. 1 Sustainable Development Goals (UN 2015b)

Whisnant 2019; Evans et al. 2017) and maintain their competitive advantage (Porter and Kramer 2006; Walsh and Dodds 2017). This reflects their capability and capacity to sustain and increase their commercial expansion without compromising their environmental responsibility. Earlier research (Epstein 2008 and Estes 2009) found clear vision with long-term strategic focus, supported by planning and direction setting, is required for effective sustainability strategy development and implementation. This is argued to distinguish successful organizations from other organizations (Aquilani et al. 2018; Baumgartner and Rauter 2017).

Organization's economic success ultimately depends on the creation of not only monetary value but also other values that stakeholders expect (Morioka et al. 2017). Organizations' profit-maximizing strategy needs to incorporate stakeholders' expectations for sustainable development to remain viable and competitive (Elkington 1997; Laszlo and Cescau 2017). For a transformation to achieve the ambitious UN SDGs, active collaboration of individuals, governments, public and private sector organizations and civil society organizations is needed. From this perspective, economic growth is not the only goal which an organization should focus on to achieve the SDGs; strategic directions need to incorporate and consider multiple perspectives of stakeholders including environmental and social impacts of the organization (Xiao et al. 2017).

Governments will have their own set of priorities, requiring businesses to implement actions to achieve SDGs. Change is critical for businesses, and requires rethinking strategy and business behaviour to align with goals, to assess and evidence their impacts (Accenture 2018; PwC 2016).

In response to this new demand for accountability, several Australian companies are now incorporating SDGs into their business strategies and reports (Adams 2017). This is also evident in the recent survey of UNGC member companies (Accenture 2018):

- 88% understand that the SDGs are relevant to their business.
- 86% believe that standardized impact metrics will be important in unlocking the potential of business to contribute to SDGs.

Sustainable development is a multi-dimensional goal, which can be approached from different perspectives; practical actions are required by businesses as organizations' efforts are vital since international business and trade has a significant impact on sustainable development from environmental and social perspectives (Xiao et al. 2017).

The motivation for selecting MIG is because this sector includes companies that manufacture chemicals, construction materials, glass, paper, forest products and related packaging products, and metals, minerals and mining companies (ASX 2018). This sector is identified as one of the most carbon-intensive industries (Neuhoff et al. 2017) and the pattern of growing demand for their material resources is likely to continue. Materials extracted from natural resources and consumed worldwide has doubled since 1980 and reached nearly 72 billion metric tonnes (Gt) in 2010 and is projected to reach 100 Gt by 2030 (OECD 2015). One of the primary issues is the environmental cost of production, which is mostly ignored. If the cost is accounted for, companies would lose 41% of their earnings on average (KPMG

International 2012). Therefore, these significant carbon-emitting industries should be studied further to understand *what* they have done and *how* they could further improve their organizational sustainability policy and strategy implementation, which in turn could improve both their business and sustainability performance. It is also important to study how the MIG can play a role in achieving the SDGs, including SDG9 (build resilient infrastructure promote sustainable industrialisation and foster innovation through its business), SDG12 (ensure sustainable consumption and production) and SDG13 (take actions to combat climate change and its impacts). In this paper we reuse a framework developed by Teh and Corbitt (2015) to strategize for improving business and sustainability performance (Fig. 2) to analyse eco-sustainability policy and strategy of companies in the MIG.

2.2 McKinsey Seven S's framework

The McKinsey 7S's framework has been adopted by companies to understand the complexity of organizations, assist them to diagnose and implement business strategy to achieve its objectives. Pascale and Athos (1981) used the McKinsey 7S's as a diagnostic tool and recognized the importance of seven interrelated dimensions for successful implementation of business strategy—strategy, structure and systems, shared values, staff, skills and style. Starik et al. (2012) developed a Strategic Environmental Management (SEM) framework by mapping to McKinsey 7S's to identify key features of company environmental sustainability profiles. Existing research on (eco)-sustainability still addresses operational and tactical levels, instead of strategic level (Sekera and Stimel 2011). Teh (2013) proposed that the McKinsey framework could be a useful tool at a strategic level where companies develop and implement their (eco)-sustainability policy and strategy. As a result, Teh (2013) built on McKinsey 7S's framework and used it as a foundation for the development of an evaluation metric to measure the level of adoption of sustainability policy and strategy, and to evaluate organizational eco-sustainability performance with the metrics.

3 Research method

In this research, a qualitative case-study research approach has been adopted, which is appropriate for investigating issues that are complex and difficult to quantify, and is used to identify concepts and insights that are needed to understand such issues (Patton 2002). First, organizations in a sample of ASX200 that appeared to be strongly committed to organizational eco-sustainability and considered to have the best practices of eco-sustainability in their respective industry were identified after undertaking an iterative process of assessment and analysis of various documents such as sustainability and/or annual reports, related to organizational eco-sustainability. Interviews were held with senior management of seven ASX200 listed companies (Creswell 2009) from the materials sector to assess *how* organizations implement their eco-sustainability strategy and *what* influences the extent of company eco-sustainability strategy implementation. Semi-structured interviews allow greater breadth than focused and "structured" interviews (Denzin and Lincoln 2005), generating rich and in-depth information and providing opportunities to undertake further discussions (Creswell 2009). The reason for selecting three companies out of the seven for interview data analysis was that they represent different industries in the materials sector: chemicals, packaging, and metals, minerals and mining. These companies revealed a focus on LCA for a holistic assessment of environmental impacts on the supply chain, both upstream and downstream. These companies have implemented LCA but have found it difficult to undertake LCA in its entirety. Based on the views of senior executives from these companies, blockchain has been recommended to potentially address some of the challenges faced in implementing LCA.

Purposive sampling method (Valerio et al. 2016) was used to select and recruit participants based on their role within companies and their involvement in strategic planning for eco-sustainability policy and strategy. Interviewees were undertaken with senior executives, who at that point in

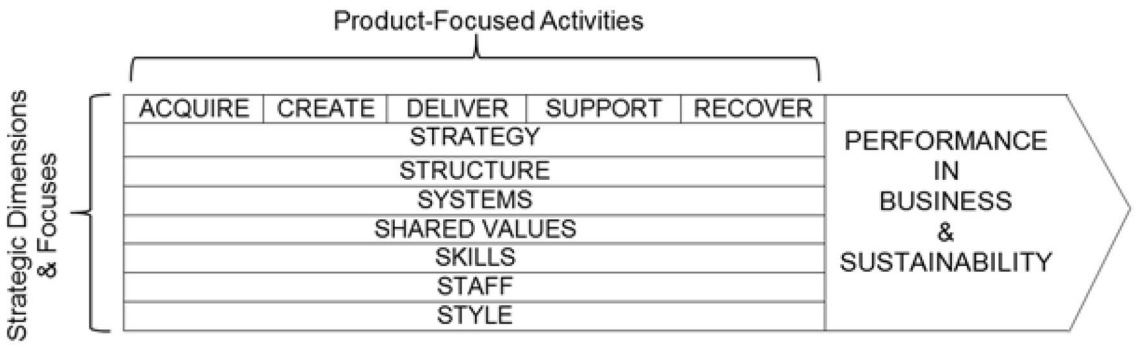

Fig. 2 Strategic focus on determining business and sustainability performance

Table 1 Participating company and participants' position

Company	Code	Position	Responsibility
1	C1	Group Sustainability Manager (GSM)	Facilitate and manage sustainability communication and engagement and report to the Boards, in relation to company's sustainability strategy, position and progress of various programs
2	C2	Director of Group Sustainability (DGS)	Develop and implement Group's sustainability and eco-sustainability strategy and programs (including LCA for products), engagement with multiple stakeholders and inspect the Group's facilities worldwide
3	C3	Group Safety and Sustainability Manager (GSSM)	Manage Group's business aspects related to sustainability, safety, health, environment, and security across business units. Implement and monitor Group's strategy, corporate governance, business processes and supply chain to reduce significant risks and prevent any adverse material outcomes

Source: Teh (2013)

time were in the roles of group sustainability or director of global sustainability. This ensured that the participants were in a position that could appraise what happened with (eco)-sustainability strategy in their respective organization and to provide in-depth responses. A list of participant profiles is provided in Table 1.

All participants were asked a series of questions (Appendix) to motivate them to share their knowledge, expertise and experience. Rich inputs generated from interviewing are believed to be vital and valuable data to improve understanding of the topic. An interpretative approach to data analysis (Yin 2009) was used because it best offers researchers more complete understanding in context-specific research as used in this study, and can provide deeper understanding of data and information than analysing ranks and counts as this approach also offers researchers better understanding of attitudes, feelings and behaviours.

4 Findings and discussions, and proposed solution

Executives of MIG companies recognized the criticality of climate change, effects on their business, and their actions, both in the short term and long term. They acknowledged the problems posed by climate change (SDG13 climate action to combat this) and argued that, it

- is important to manage and mitigate risks associated with climate change as the company has operations worldwide and is one of the largest carbon dioxide emitters in Australia;
- represents a significant threat to business continuity and company's ability to deliver and meet customers' expectations;
- possesses some significant physical risks to the business, which have created serious financial impacts on the business;
- provides an opportunity to maintain the company's competitive advantage; and
- is an opportunity for the business to rethink about the business and how it can integrate sustainability into the business.

Using the framework (Fig. 2), the discussion begins with strategic dimensions *not* directly included in the *product-focused activities (product life cycle)*, but with what value can be directly created by driving sustainability efforts, supported by other dimensions in the framework.

4.1 Applying the McKinsey 7S's framework

4.1.1 Strategy

All three companies considered different types of integration of eco-sustainability and business strategy. For example, the focus of [C1] eco-sustainability strategy was on carbon emissions and water. Company [C1] installed greenhouse gas (GHG) abatement technology at its Australia's plants. Company [C1] also invested in a groundwater treatment plant to cut its heavy reliance on potable water usage; which has reduced by approximately 80% to 90%. This was all integral in their eco-sustainability strategy.[C1] GSM further pointed out that the formulation and implementation of their eco-sustainability strategy also considered its business supply chain whereby working closely with customers has become even more important—not just supplying the product, but the expertise and knowledge on how to use products more efficiently can contribute to the overall sustainability strategy.

The same sentiment was echoed by the DGS of [C2] which worked closely with customers to identify the most sustainable packaging options.[C2] conducted a product LCA because 90% of the environmental impacts resulted from a combination of goods production and packaging process. As part of the strategy, the GSSM of [C3] stated, "We are focusing on what is material for the Group. We look at our operations, particularly waste to landfill from our factories and water usage. We identify 5 or 6 key areas for our business where we can drive improvement".

4.1.2 Structure

The respondents reasoned that having an eco-sustainability strategy is important, but having corporate *structure* and *systems* that provide coordination, communication and governance is equally important if one is to successfully implement their eco-sustainability. A centralized organizational structure is considered suitable to [C1] as it can eliminate business units working in silos and streamline all business units to support the creation of a clearer path for organizational eco-sustainability. It is also the result of the recent corporate restructuring. But, the GSM [C1] stressed that, "we really need to think about how to integrate sustainability into the everyday business where people think about sustainability in their work. And, we need to understand how strategy is cascaded and implemented, and how companies create more specific targets to achieve the objectives. This will then help to develop the best [sustainability] practices".

The other two participating companies, each have a dedicated team of sustainability specialists or environmental professionals to advise and support the business in policy and strategy implementation. One has a sustainability leader sit within each of the six business groups who have the responsibility to contribute to organization's eco-sustainability [C2].[C3] is assisted by a sustainability manager and 30 full-time equivalent staff from various business units to support the groups' sustainability initiatives. Further added by GSSM [C3], "… having this structure is to ensure that we are focusing on our limited resources on the material area of significance and material to our business".

4.1.3 Systems

Company [C1] embedded its carbon emissions accounting into its current enterprise system. To engage with internal stakeholders, [C1] released quarterly internal sustainability newsletters and published updates on its intranet; further commented, "…it is very easy to have goals, and aspirations about [sustainability], [but] it is about being measurable. So, I think, it is crucial to [measure]… to track performance and be visible. To have a baseline data and set goals is of foremost importance.[Then], we must be able to collect data and report upon the meaningful data. We have systems for collecting things like energy use, waste, production, water uses, wastewater and GHG".

Likewise, the DGS of [C2] emphasized the importance of having a system, for example, the company invested in a document-sharing platform to manage data across six different business groups and to enhance the quality of data—integrity and authenticity. The environmental management system (EMS) are International Standard ISO 14001 certified. The GSSM [C3] agreed that having systems is important, to align staff performance with company's objectives. However, [C3] said "the ISO14001 certification (EMS) is not a big priority for us, we don't see a lot of value in it, unless our customers do".

4.1.4 Shared values

For [C1], shared values *of being sustainable* was promoted to become a zero-harm, zero net carbon emissions and zero potable water use company. GSM [C1] stressed that it was a long-term aspiration, and admitted that the challenges towards a zero net impact was not easy. But the manager was confident that they were making good progress on their plans when the objectives are clear.

In the opinion of DGS [C2], shared values that foster organizational innovation culture can contribute to eco-sustainability. Innovation was supported by continuous experimenting, research and development to improve product development that lowers negative impacts. To do that, [C2] highlighted, "… innovation is somehow embedded in some part of the business, supported by shared values".[C2] further suggested that "… embed performance requirements into sustainability scorecards". This is supported by *systems* discussed earlier.

The discussion by participants was that creation and communication of shared values of being eco-sustainable should be integrated with its core business, corporate strategy and vision. Stakeholder engagement has been shown to be important when a company formulates its shared values (Teh and Corbitt 2015), since stakeholders are actors that may support or hinder strategies implementation (Michelon et al. 2013).

4.1.5 Skills

Executives from the participating companies agree the importance of having staff with the capabilities, skills, knowledge, experience and tools that they need to contribute to company's eco-sustainability strategy implementation.

Hence, they offer a variety of sustainability management training and development programs to their staff. The GSSM [C3] said: "Within the business, we constantly develop and train them. The company also offers a management training program that improves the staff skill sets and knowledge in relation to organizational eco-sustainability policy and strategy. So they can understand *why we do it and how we do it*".

According to the GSM [C1], company provided a variety of training programs—*skills* and tools such as Hazard and Operability (HAZOP) and Sustainable Operations (SUSOP). These risk management tools were a methodology that could be used by staff to identify potential risks associated with any sort of project.

4.1.6 Staff

Staff with various experience and skill set from different management levels could be the key to support organizational eco-sustainability policy and strategy implementation. Their experience and skills can be utilized to achieve organizations' sustainability objectives set across different business divisions. The GSM [C1] saw the role played by staff as crucial in developing a sustainability focus mindset. Companies need to effectively engage with staff to get organizational sustainability values embedded within the company culture or DNA.[C1] further added, "you really have to engage your staff through an organization's core values. It is about trying to get everyone on board with the thinking and mindset; and engagement with staff and customers is definitely a big area for improvement". A similar viewpoint was shared by DGS [C2]: every staff member has the same responsibility for driving and improving the company's eco-sustainability initiatives and performance. But, as a sustainability leader in the company, the leader has more accountability and responsibility to spearhead and drive company's eco-sustainability strategy implementation [C2].

Another challenge was about hiring the right staff who are passionate about sustainability. Organizations can provide staff with additional training and development as required but they must also ensure that the *shared values* of the organization are well embedded within the training programs. This strategy was considered necessary so that the staff could be the *Green Champion/Green Catalyst* to share their knowledge with their peers and lead the organization's eco-sustainability initiatives.

4.1.7 Style

Support and commitment of the CEO and senior management was considered indisputably important by all participating companies (Teh and Corbitt 2015). The Board in [C1] relaunched the company's eco-sustainability strategy. The newly appointed CEO initiated organizational restructuring, and created a senior executive position to oversee and manage the company's corporate sustainability [C1]. The GSM [C1] thought "it is a real statement of intent of the Board that they are taking this (sustainability) seriously and showing their support for sustainability within the company. That's the top-down approach".

Evidently, without the support from the Board of [C1], engagement and communication about sustainability within business would be absent. This was evidenced in [C3], the change of leadership led to a lack of strategic direction in organizational sustainability. Without any clear and strategic direction, the implementation of eco-sustainability policy and strategy was stalled to a degree. It became more challenging to engage staff at all levels within the organization, even though there were *structure*, *systems*, and *shared values*.

This research has uncovered how the MIG companies implemented their eco-sustainability policy and strategy; mapping each dimension within the 7S's framework; and how each dimension intertwined and interacted within the 7S's framework. Companies could consider different corporate structures that suit them in order to facilitate the implementation of an eco-sustainability strategy. Participating companies also looked to invest in systems that can improve data integrity and reliability, where decision-making processes require timely data and reports. They believed that clear shared values were important, without them, they could find it even more challenging to engage with key stakeholders in creating a sustainable organization. The senior executives of the participating companies agreed that their respective organizations need to provide relevant training and development programs to support their staff.

Nevertheless, senior executives of the ASX200 MIG companies believed that *strategy* remained their core focus in a successful implementation of sustainability-related initiatives. The outcomes of this research supports the proposition that (eco)-sustainability strategy be incorporated into business strategy as demonstrated in the responses reported in the interview data, and they should be implemented at an enterprise-wide level, holistically. This will enable organizations to be more effective in utilizing their resources to facilitate the implementation of (eco)-sustainability policy and strategy. Organizations can meet and address both business objectives and sustainability agenda and SDGs without compromising their economic purposes.

4.2 Management and governance

The discussion, based on the interview data, has mainly focused on the *management and governance of sustainability*. Key considerations which have been covered including

having a strategy and policy to support sustainable development and SDGs. Relevant roles at the higher levels of governance such as a sustainability officer or a team who is dedicated to executing their responsibility has been determined as crucial to the success of undertaking sustainable development supporting planning and execution. Systems, employees' skills, organizational culture and commitment are all internal foci to promote sustainable development.

From an internal perspective, it would have been useful to get deeper insights into business operations and processes for improvements through LCA. It is these processes which utilize resources and can create negative environmental impacts such as large quantities of waste generation, pollution of water and air, and negative impacts on biodiversity and eco-systems which companies in the materials sector, for example, mining or chemicals production companies need to consider from the perspective of innovation for improvement purposes and sustainable development. This is where companies in the MIG can play a role in achieving the SDGs, for instance, SDG9, SDG12 and SDG13.

On the other side of the equation—the supply side, the key medium of impact of an organization takes place via the most prominent external connection which an organization has, that being the goods/services which are provided by an organization to its customers, which can be highly environmentally sensitive. Part of the same model (Fig. 2.) that recognizes the dimensions is the ubiquitous spread of associated *product-focused activities*, namely to acquire, create, deliver, support, and recover. These product-focused activities are supported within the 7S's. Each of these activities is integral to the strategic dimensions of the model. The sustainable activity model looks at activities related to organizations' products throughout their life cycle, from acquisition of raw materials through to recovery or disposal (McPhee 2014).

The following discussion focuses on *product-focused activities* which can be mapped to LCA. Through LCA, organizations are able to develop a comprehensive understanding of the product/service life cycle; and those forward-thinking and innovative companies could rethink about the materials used and product design, as well as the business model. This can provide organizations with a first mover competitive edge, if they are making a shift from the linear economy to the circular economy (Lacy and Rutqvist 2015).

In a company moving towards achieving the SDGs, there is a need for comprehensive and robust tools to manage performance and identify solutions that best support sustainable development and help in the decision-making process. Decisions must have a system perspective; consider the life cycle, and all relevant impacts of a product or service. LCA (see ISO 14040:2006 EM-LCA) is a tool that has these characteristics to serve the purpose of undertaking a holistic understanding of a business' environmental impacts (Hauschild et al. 2018). In addition, there is significant business value when the SDGs can be reached as agreed, but companies are struggling with how to do this. Hauschild et al (2018) identify the gaps and needs, and explain how LCA can contribute to meeting these needs. This is done through the projects that link the SDGs to life cycle impact pathway frameworks (Weidema et al. 2018).

Similarly, this research is interested to explore that domain. As described in the interview findings and discussions, key focus is on management and governance but the capabilities of LCA that provides a holistic assessment of environmental impacts of products, from upstream and downstream perspectives, is under-explored. On one hand, it is important for companies to be accountable for the use of their products, for example, in this case, the materials sector by their customers. Yet, enforcing accountability in the supply chain downstream has been difficult; blockchain has the potential to help enforce accountability.

4.3 Life cycle assessment (LCA)

LCA is a methodology that allows a company to estimate the cumulative environmental and social impacts associated with manufacturing a product or delivering a service, thereby providing a comprehensive view of the potential trade-off in environmental and social impacts associated with a given activity (Gonzales 2018; Linkov et al. 2017). LCA examines the impacts of a product on the environment by accounting for all processes starting from converting inputs to outputs throughout the product's life cycle. Different stages of the product life cycle include: its birth, design, raw material extraction, material production, through to its use and final disposal (Gonzales 2018).

The concept can also be used to optimize environmental performance of a single product or that of a company. As a result, LCA can be a valuable method to identify inefficiencies, which can lead to improved productivity and reduced negative environmental impacts (CSIRO 2018). This often referred to as life cycle sustainability assessment (Edge Environment 2018). This can better inform sustainable procurement, product development and innovation, green marketing and reporting, and overall sustainability strategy development. LCA is used to assess environmental impact of products, processes or services from raw materials to the waste stage of the product (Andersson et al. 1998). An important step in the implementation of LCA to achieve sustainable development is to identify "hot spots" in the life cycle which are critical regarding environmental impacts (ibid.) Socio-ecological principles can be embedded in each

of the four steps of LCA (being goal and scope definition, inventory analysis, impact assessment and improvement assessment (Ortiz et al. 2009). The mapping of sustainability embedding in LCA steps provided below is based on a method used previously by Andersson et al. (1998).

Step 1: Goal and scope definition The aim here is to embed sustainability perspectives in the development of products and processes. From the perspective of socio-ecological principles, this step means that the use of fossil fuels and mining should be drastically reduced. The use of substances which have a detrimental impact on nature must be phased out as they are not part of nature. There should be more efficient and careful use of productive areas for agriculture, fishing and forestry; and infrastructure development should be carefully planned for this purpose. Technical and organizational efficiency should be increased with more resource efficient lifestyles. From a service perspective, use of alternative strategies for products and processes to promote a sustainable society should also be considered.

Step 2: Inventory analysis Each stage from ecosystem manipulations to extraction of raw materials, to production, transport, consumption and waste management phases need to be considered to understand environmental impacts, from upstream to downstream.

Step 3: Impact assessment A grading system should then be applied to identify potential hot spots. Negative scoring should be applied to flows and manipulations that create environmental problems. Hot spots which threaten long-term productivity and biodiversity need to be negatively scored; and low quality services, systems (products and processes) which do not fit within a sustainable society and that utilize old technologies and cause organizational inefficiency need to be considered for phasing out.

4.3.1 Case Companies LCA Application

Some degree of LCA application can be demonstrated through the case companies, for instance, [C3] agreed that, although product stewardship and LCA are particularly complicated and expensive processes, the company still do it to innovate its process. The GSSM [C3] further stressed that:

> … We are certainly doing LCA to help [us] to understand the carbon footprints and how some of the raw materials go into our products. So, the best example is one of our products which contains a lot of titanium dioxide. To get titanium dioxide into a form so that they can be used in our product, it is a very energy intensive process. It also represents about 25 per cent of the cost of making the <product>. We did not have that understanding previously, but we know that, in the longer term, if we want to improve carbon footprints of our products, we are going to focus on titanium dioxide. LCA probably has not helped us a huge amount in the shorter term. However, as you would know this is kind of a longer-term view. It is about what improvements and changes can we make in the next twelve months and up to three years.

Similarly, LCA was considered important for [C2]. The company has an in-house proprietary LCA tool to support the work in evaluating Post-Consumer Recycled Polyethylene Terephthalate bottles. This was a centralized tool, which was shared across different businesses to access and use the data. LCA allowed the company to evaluate the impacts of each material and decide the best option for production, in terms of both costs and benefits. Research has shown that organizations which conduct LCA of the products/services can potentially increase the value and efficiency of their production and business activities, such as, raw materials utilization, alternative energy consumption (Bourtsalas et al. 2018), better waste management (Gong et al. 2018) and creation of innovative eco-design/eco-efficient products, brand reputation and customer loyalty enhancement (Ahmad et al. 2018; Chang et al. 2014).

Organizations with good sustainability practices and environmental management can create better shareholder value and improve overall financial performance (Sroufe and Gopalakrishna-Remani 2018). This practice was evident in company [C1] which was constantly looking for better alternatives for production, as part of its eco-sustainability strategy. For example, recycling and utilizing waste—used lubricating oil or hydraulic fluid for company's vital machinery and equipment. The company was essentially reprocessing its own waste to reduce the use of raw materials in its business operations. This offset the energy used in the production. This was good for that business's bottom line as well. The interviewees emphasized the importance of aligning (eco)-sustainability strategy with overall business strategy supporting an existing view that both sustainability and business strategies should be integrated so that they do not become competing interests (Teh and Corbitt 2015).

4.3.2 Challenges to implement LCA

Although LCA is a powerful tool and methodology, there are some limitations in its application (Ekener et al. 2018). First, approximately 70–80% of the time and cost of an LCA can be attributed to data gathering for the inventory phase (Miah et al. 2018), especially with full LCA undertakings (Yavuz et al. 2018). This is evidenced in the case companies studied here. Further, it can be even more expensive when data are not readily available or if one's knowledge of the

system under study is limited. Consequently, this will not only increase costs when large amount of data is required (van der Meer 2018) but also increase the *uncertainty associated with data availability* when one must either make some assumptions about the data source or to utilize averaged data (Gonzales 2018). When LCA studies depend on assumptions and scenarios to assess real-world problems in a simplified model, it can create scepticism about LCA results (van der Meer 2018). This will impact the credibility and usefulness of the data for decision-making.

Due to inherent limitations in LCA, transparency about the assumptions and data quality for data used in the assessments is questionable (Gonzales 2018), especially, data gathering in social LCA (Norris 2014). On one hand, to gather all the necessary data to carry out the assessment is a challenging task and can be prohibitively expensive and often secondary data cannot cover the lack of information about all the processes under study (Fauzi et al. 2019). One the other hand, even though information about social impacts of products gathered in downstream supply chain is based on sustainability standards and certifications; the verification of these claims requires costly and time-consuming auditing process (Mieras et al. 2019).

Since LCA is an iterative methodology, data transparency is required to greatly help bolster the credibility of the assessments and make it easier to constantly integrate up-to-date data in providing accurate and reliable information to support decision-making (Björklund 2002; Gonzales 2018). LCA requires validation to ensure credibility of information reported and exchanged. This can involve a network of reviewers along the value chain, or third-party, which can be another complex and expensive process.

LCA can be a useful, yet complex, methodology or expensive tool to use, given many stakeholders are involved in interdependent activities along the value chain. However, emerging technology such as blockchain, can be a powerful complementary lever that is able to bring together stakeholders, from acquirer, creator, intermediaries, to end consumers in LCA analysis and implementation. Blockchain can efficiently validate information digitally, facilitate coordination and better streamline activities. This can enable product-focused activities to be more transparent and sustainable; this technology can help addressing the limitations of LCA to a certain extent, by sharing immutable and irreversible information in real-time to meet the information requirements and decision-making process of a contemporary business.

4.4 The potential of new technology for sustainability strategy

One of the emerging technologies is blockchain which has enabled the creation of decentralized currencies (e.g. Bitcoin) (Nakamoto 2008). Worldwide spending on blockchain solutions is forecasted to reach US$11.7 billion by 2022 (Seth 2019).

4.4.1 Blockchain

Blockchain, also known as distributed ledger technology (DLT), consists of a distributed peer-to-peer network of computer nodes that maintains a decentralized shared database of records. These transactions or digital events are verified and updated in real-time by consensus of participants in the system, without the need for central verification (Iansiti and Lakhani 2017; Shen and Pena-Mora 2018).

The algorithm or distributed consensus protocol is one of the important aspects of blockchain, as it provides a secure mechanism for electronic collaboration without relying upon a central authority for trust (Swan 2015). The peer nodes agree on the validity and the sequence of transactions. As each transaction occurs, it is placed into a data structure called “block”. Each block is connected to the previous and added to the next in an irreversible chain and transactions within respective blocks to the shared database to form a linked chain, hence the name “blockchain”. Each block in the blockchain has its own timestamp and a cryptographic hash that connects the new block to the previous block. Hence, blocks can only be appended, not deleted (Iansiti and Lakhani 2017; Shen and Pena-Mora 2018).

The outcome of this is a shared database with an ever-growing list of records that are immutable and irreversible; tampering of any block information can be detected by peer nodes on the blockchain. Since it is a write-once, append-many technology, making each transaction verifiable and auditable. Blockchain can enforce transparency and guarantee eventual system-wide consensus on the validity of an entire history of transactions (Risius and Spohrer 2017). It enables exchange of value and sharing of data in a secure environment (Gilbertson et al. 2016).

There are variations in how distributed ledgers are structured, controlled and governed (Zachariadis et al 2019). These differences reflect the degree to which participants in a network are trusted. There are two types of blockchain networks: permissioned and permissionless (Xu et al. 2017). Permissioned networks (e.g. Hyperledger Fabric) are those where a limited number of trusted entities have gained permission to join the network to validate transactions. For example, the Linux Foundation (2018) Hyperledger Fabric is a well-known permissioned blockchain and provides multiple algorithm options for the consensus process. It may also provide full smart contract capabilities. In permissionless networks (e.g. Bitcoin and Ethereum), any individual can validate transactions as no permission is required to join a network. It may allow transactions to be validated pseudonymously (Capgemini 2015; Shen and Pena-Mora 2018).

4.4.2 Potential and application of blockchain

Participating companies in this research acknowledged the importance of exploring and utilizing technology that can help them to achieve the company's vision—being sustainable. Although creating a new system for supporting eco-sustainability is not always necessary (Teh and Corbitt 2015), blockchain offers different opportunities for companies that can help to address the limitations identified in using LCA. For example, Mieras et al (2019) propose to use blockchain or internet-of-things sensors measuring emissions, energy use, or other relevant inputs for LCA models in the Dutch Dairy Farming Sector which originally started using a cloud-based LCA tool that incorporates big data into LCI data gathering through an application program interface (API).

Information and Communication Technology (ICT) is highly correlated with country-level SDG performance (89%), which suggests that countries that perform well on ICT perform equally as well on SDGs (Huawei 2018, 2019). Artificial intelligence and blockchain technologies can transform economic systems towards more sustainable models (ibid.).

This research proposes the use of blockchain by the three case companies to attain sustainability and achieve SDGs through a complete implementation of LCA. Blockchain can potentially address the limitations inherent in LCA, especially the challenges associated with *integrity, traceability and transparency* of data, given that many stakeholders are involved in complex interdependent activities along the value chain.

For the purpose of this paper, blockchain is included in the *systems* dimension of the framework shown in Fig. 3. This is because blockchain is a technology that is part of the interconnected information systems that supports business functions and internal processes.

In the context of sustainability, blockchain-enabled solutions are expected to improve the reliability of data related to supply chains and to help businesses eliminate waste and hazardous activities (WEF 2018). WEF (2018) report identifies more than 65 ways blockchain can be applied to the world's most pressing environmental challenges. These range from decentralizing management of natural resources such as energy and water, to creating more transparent supply chains. For example, blockchain provides accountability and transparency to enhance visibility along complex supply chains to cut food waste (Ahmed and ten Broek 2017) and improve the green electricity market (Keshav 2018).

There are multiple applications of blockchain in product life cycle or supply chain, for example verifying proof of fair payment, proof for sustainably sourced and slavery-free products to demonstrate compliance with legislation and voluntary initiatives to reduce impacts; also through certification and generation of interactive-labelling for better informed product choice (Provenance 2019). Another example is Insolar (INS 2017) which is a blockchain-based platform that allows grocery manufacturers to join and sell their products and customers can buy and save up to 30%, while eliminating as much as 130 million pounds of food waste annually.

Furthermore, blockchain can be used to implement sustainability-related controls, for instance, implementing management systems and internal KPIs relating to sustainability, managing company's certifications and risk-safety-related issues (Campos and Rebs 2018). This can benefit the case companies in this research—companies can implement more robust supply chain management practices that can better track the products along the supply chain, supported by blockchain-distinguishable features of traceability and transparency.

Blockchain can improve both social and environmental aspects of organizations that may help them to achieve SGDs at an accelerated speed. Mendling et al. (2018) argue that blockchain have the potential to change the environment of inter-organizational processes, and their associated activities when they are better streamlined and operated. To this point, we have seen that there is a clear need to understand

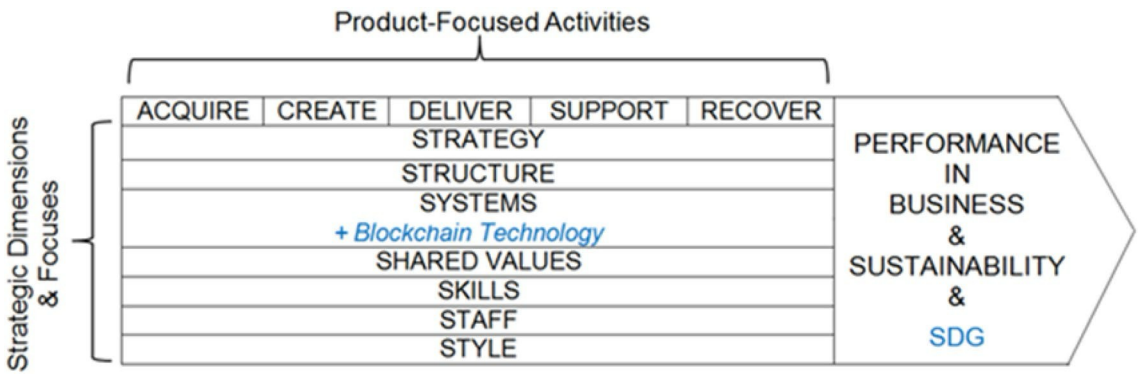

Fig. 3 Strategizing Sustainability with Blockchain Technology for SDGs

the processes of an organization in relation to the activities in sourcing and using resources, the production of services and products, and as a result, the generation of waste at the end of the product life cycle.

4.4.3 Blockchain and LCA: case of implementation in the materials sector

The main characteristic of Blockchain which can serve an extremely useful purpose for sustainability in LCA is its transparent and open nature. Using blockchain technology, an LCA of products can be completed using actual product data and real-time data, rather than estimated values, such as in current LCA methods (Favi et al. 2018). With LCA, products can be tracked across global supply chains; and specifically for the inventory analysis stage of LCA, corresponding to environmental and/or social impacts can be clearly identified (Herrara 2017). Blockchain can be used to verify that standards are being implemented upstream and downstream in the supply chain regarding various sustainability-related factors such as living conditions of workers, wages and environmental impacts (ibid.) This accurate and actual information is a revolutionary contribution of blockchain technology in the LCA domain (Kouhizadeh and Sarkis 2018).

Blockchain also has the potential to promote accountability and ethical behaviours on behalf of various businesses involved in the supply chain (Adams et al. 2018). Use of raw materials (natural resources) and environmental and social impacts of products developed and sold by MIG companies have been criticized on numerous occasions and accountability for related impacts has been pushed (General Services Administration 2019; Sustainability Victoria 2019). Further, connecting blockchain to various source systems such as ERP and SCADA can simplify data gathering across the carbon supply chain, thereby improving the transparency and visibility at lower cost, time and effort (Banerjee 2018). Main benefits of using blockchain for LCA and specifically for the inventory analysis step in the LCA include: Costs and time reduction due to less planning for organizing data collection at multiple locations, a free and transparent database due to distributed networks, decentralization, requiring minimal administrative structures for basic functioning of the database (Herrara 2017).

Blockchain can be used in MIG companies as well as in other environmentally sensitive industries that undertake a complete LCA to help facilitating the achievement of SDG9, 12 and 13. To a greater extent, this can help in achieving multiple targets under SDG12, including, SGD12.2 sustainable management and efficient use of natural resources; SDG12.4 environmentally sound management of chemicals and all waste throughout their life cycle; SDG12.5 reduce waste generation through prevention, reduction, recycling and reuse; and SDG12.8 provide people with relevant

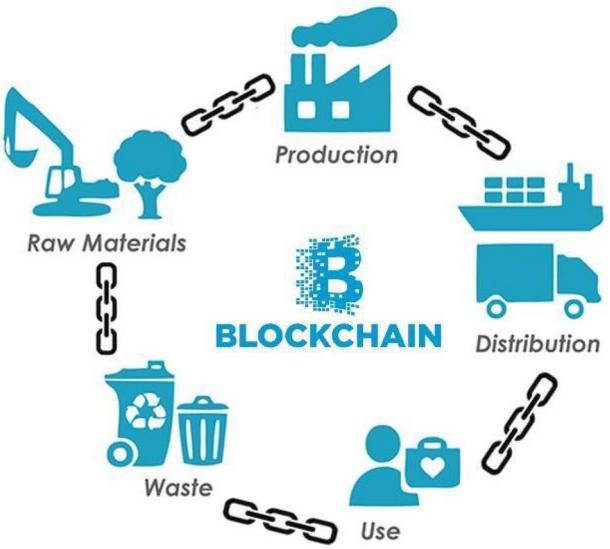

Fig. 4 Blockchain for LCA (adapted from The LCA Centre 2019)

information and awareness for sustainable development and lifestyles. Blockchain can help these companies to better understand their product/service life cycle so that they can be more sustainable in their production, consumption, and overall business activities. They can identify inefficiencies, which can lead to improved productivity and reduced negative environmental and social impacts (Fig. 4). If blockchain can deliver its full potential as it promises, it can contribute to organizations at the strategic level for sustainability strategy development, and product innovation, easier and faster (Fig. 3).

Blockchain can help with implementing LCA for sustainability as follows. Blockchain can be used to track the origins and movements of products; inventories can be tagged with related environmental information such as results of environmental product declarations and carbon accounting information (Sinistore 2018). One of the prominent companies in the materials sector, BHP (a major mining company) now requires (as world first) its customers to cut GHGs; is targeting shippers, steel mills and power plants (Toscano 2019). This is a major initiative by BHP to target Scope 3 emissions (ibid.). In addition, with actual applications in the materials industry for LCA and specifically for inventory analysis step, the following additional examples shed light on the immense potential for sustainable development in the MIG.

4.4.3.1 Plastics: resin suppliers domo and covestro The company is teaming up with blockchain start-up Circularise for circularity in the plastics industry. The protocol enables trusted data exchange in supply chains without public disclosure of data sets or supply chain partners, thus protecting

sensitive information (Moore 2019). The partners believe that achieving traceability and transparency in the plastics supply chain enabled by blockchain will make it more authentic and transparent. There are three main objectives: Choose Circular, Produce Circular and Make Circular. However, the key weakness associated with the set up at present is the amount of energy consumption per transaction on the Ethereum network (ibid.) Ethereum is planning to transition to a new mining model—proof-of-stake (PoS),which reduce energy requirements by 90% (Moore 2019).

4.4.3.2 Blockchain for sustainability in mining Ford is piloting the first blockchain project tracing cobalt supplies from the Democratic Republic of Congo (DRC) which produces over 60% of world supply and has major human rights violations issues (Uzsoki and Corneau 2019). In partnership with Huayou Cobalt, LG Chem, RCS Global and IBM, IBM Blockchain Platform is being used to create a simulated scenario in the supply chain. Cobalt production is tracked from DRC to smelting in South Korea and then sent to Ford plant in the United States. Blockchain can help to eliminate the sourcing of cobalt from operations connected with human rights abuses (Uzsoki and Corneau 2019). It can trace any types of negative economic, social and environmental issues associated with the inventory analysis step of LCA.

As suggested in Fig. 4, blockchain has the potential to generate greater transparency and verify information in all steps of the value chain; it can serve a particularly useful function in helping businesses and users (customers) to demonstrate that they are curbing their carbon emissions. Blockchain can serve as an accountability function, from upstream to downstream, and vice versa.

5 Conclusion

This paper has investigated the structural parameters that impact how MIG companies implemented their eco-sustainability policy and strategy, and has proposed an additional dimension to that structure, the adoption of blockchain. The focus of the research was to address the question: how can blockchain address the challenges companies in MIG face in implementing LCA and facilitate a more effective implementation of LCA as part of their eco-sustainability policy and strategy? The major contribution of this paper in answering that question is that it revisits the framework developed by Teh and Corbitt (2015) and introduces blockchain within the systems of the framework. This paper also adds to the growing literature on blockchain applications for sustainability. The paper has shown how blockchain can be used in LCA to support each of the activities. The analysis shows that blockchain can be a powerful complementary lever that is able to bring various stakeholders together, from acquirer, creator, intermediaries, to end consumers in LCA analysis and implementation. Blockchain can efficiently validate information digitally, facilitate coordination and better streamline activities. This can enable product-focused activities to be more transparent and sustainable; this technology can help addressing the limitations of LCA to a certain extent, by sharing immutable and irreversible information in real-time to meet the information requirements and decision-making process of a contemporary business (Favi et al. 2018; Gonzales 2018; Mieras et al. 2019).

The outcomes of the analysis in this paper supports an argument for organizations to further explore and examine potential blockchain-enabled solutions for sustainability, which might help them in achieving SDGs. Specifically, this research seeks to understand the use of blockchain in LCA to address the challenges associated with integrity, traceability and transparency of data; limitations inherent in LCA, given that many stakeholders are involved in complex interdependent activities along the value chain. This process seemingly might result in solving the most critical environmental issues, social inequality and promoting global sustainability.

Although blockchain can be beneficial to many organizations in addressing SDGs, it is important to note that for companies to create value, they need to systematically link blockchain with their strategy and capabilities (Felin and Lakhani 2018). Therefore, blockchain is added and discussed as an element in the *systems* within the 7S's framework (see Fig. 2). This research notes, specifically, to implement successfully use of blockchain in the LCA, incentives need to be provided to stakeholders involved in the value chain to be transparent. If adoption is not widespread, blockchain becomes less powerful (Felin and Lakhani 2018).

6 Limitations and future research

These outcomes, however, are tempered by consideration of limitations associated with blockchain studies and application, such as infrastructure required, risk, privacy, costs and scalability. Although blockchain-enabled LCA can be a powerful lever that can bring together stakeholders and streamline these complex activities. Still, each of these stakeholders might want to retain unique governance mechanisms and structure, where institutional arrangements, decision-making protocols, and stakeholder engagement requirements

shape and limit the types of activities that are acceptable and useful (Trump et al. 2018). Some considerations should be given to developing a fuller understanding of the role of ownership (decision control rights) in the integration of blockchain with LCA? How are decision management rights allocated? The stakeholders might question who is allowed to decide, what kind of decision to be made, and under what circumstances? Is decision-making rights help by the same individuals? In short, this raised the question of whether a centralized decision-making body should retain control over the ledger.

In addition, whether information within the ledger should be publicly (decentralized) or privately (centralized) available for access also needs to be considered. This is because blockchain technology would facilitate information sharing through LCA activities; some stakeholders may assume information as a competitive advantage which makes them unwilling to share valuable and critical information (Saberi et al. 2019). The hesitation to reveal information from some stakeholders may limit the full benefits of adopting blockchain technology and hinder the successful implementation of blockchain-enabled LCA (Saberi et al. 2019). Given that many stakeholders are involved in complex interdependent activities, blockchain deployed by each of these stakeholders would likely need to be modified. Also, the concern of the role of ownership together with publicly or privately available for access further raises the governance challenge of which types of blockchain to be deployed—'permissionless' or 'permissioned' blockchain (Beck et al. 2018; Trump et al. 2018).

In terms of future research, further work is required to explore this exciting research domain further. Potential application and improvement areas include studying how the case companies use blockchain-based LCA. Future research should focus on the integration of blockchain with LCA framework, and case companies would be a valuable contribution to the knowledge and practice. Future research may also investigate the barriers of implementing such a blockchain-based LCA, particularly to explore and address the limitation raised in this paper—on implementation of effective governance mechanisms and structure. Nevertheless, this research offers a first step towards providing a sound basis for future research on blockchain-enabled solutions for sustainability which have the potential to help organizations to explore this novel technique for greater transparency and verifiability, working with relevant stakeholders to achieve the ambitious SDGs, collaboratively.

Appendix

Interview Questions

Section 1: General Questions

1. How important is "climate change" to your organization?

2. How do you think your organization can further improve its organizational eco-sustainability performance? (For example, reducing the intensity level of carbon emissions, offering more eco-sustainable products, adopting a more energy efficient business processes).

Section 2: Main Study Questions

S1. Strategy

1. What eco-sustainability strategies have or are about to be implemented in your organization? Please provide examples.

2. How does your organization operationalize the eco-sustainability strategy? Whether eco-sustainability strategy is formulated and implemented by integrating into your business operations? Please explain and provide examples.

S2. Structure

1. How does your existing organizational structure support its eco-sustainability strategies? Please explain and provide examples.

2. Why do you think it's important to have such an organizational structure?

S3. Systems

1. How important is your organization's systems (e.g. internal rules and procedures, ISO 14001 environmental management systems (EMS), information technology, information systems, performance measurement, reward systems and other relevant systems) to support your organizational eco-sustainability strategies? Please explain and provide examples.

2. How does your organization decide what type of systems to invest in and when to invest? If your organization has or has not invested, why/why not? Please explain and provide examples.

S4. Share values

1. How important do you think it is for an organization to have shared values with respect to organizational eco-sustainability strategies?

2. Do you think sharing of eco-sustainability best practices and strategies is strongly embedded in your organization's culture?

S5. Skills

1. How do you support the staff for whom you are responsible for with respect to organizational eco-sustainability?

2. How important it is to have staff with the capabilities, skills, knowledge, experience and tools that can contribute to organizational eco-sustainability strategy implementation?

S6. Staff

1. What is the key role played by staff to support your organization's eco-sustainability strategy implementation?

2. Why do you think the role played by staff is important for your organization's eco-sustainability strategy implementation?

S7. Style

1. What has the Board (and/or senior management) done towards developing and implementing organizational eco-sustainability policy and strategies? Please explain and provide examples.

2. How supportive is the Board and/or senior management towards organizational eco-sustainability? Please provide examples.

3. How important do you think the role played by the Board and/or senior management is in the implementation of the organizations eco-sustainability strategies?

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