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Conceptualising A Circular Framework of Supply Chain Resource Sustainability

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Conceptualising A Circular Framework of Supply Chain Resource Sustainability

Abstract

Purpose: In response to calls for conceptual frameworks and generic theory building towards the advancement of sustainability in supply chain resource utilization and management, this paper advances a circular framework for Supply Chain Resource Sustainability (SCRS), and a decision support methodology for assessing SCRS against the backdrop of five foundational premises deduced from the literature on resource sustainability.

Design/ Approach: Taking a conceptual theory building approach, the paper advances a set of SCRS decision-support criteria for each of the theoretical premises advanced, and applies the Theory of Constraints to illustrate the conceptual and practical applications of the framework in SCRS decision-making.

Findings: This study uses recent conceptualizations of supply chains as ‘complex adaptive systems’ to provide a robust and novel frame and a set of decision rules with which to assess the interconnectedness of environmental, economic, and social capital of supply chain resources from pre-production to post-production.

Research Implications: The paper contributes to theory building in sustainability research, and the SCRS decision framework developed could be applied in tandem with existing quantitative hybrid lifecycle and input-output approaches to facilitate targeted resource sustainability assessments, with implications for research and practice.

Originality/Value:

The novel SCRS framework proposed serves as a template for evaluating SCRS and provides a decision support methodology for assessing SCRS against the five theorized foundational premises.

Keywords: Resource Sustainability, Production Operations, Supply Chain Management

Classification: Conceptual paper

1. Introduction

The United Nations Social and Economic Commission for Asia and the Pacific (UNESCAP 2008, p9), defined sustainability as “the capacity of economic growth processes and social change to ensure that natural resources are not depleted faster than they can be regenerated”. For decades, the United Nations along with several of the world’s largest production economies have implemented policy directives on resource sustainability, emissions reduction, and effective waste management. These policies were developed to motivate a shift from the current linear ‘extraction-use-disposal’ approach to resource utilization, to a more circular approach with alternative pathways for by-products, emissions, and waste (Huysman et al., 2015). While these policies have increased stakeholders’ awareness on the impact of resource sustainability, there are remains challenges in implementation, due to the difficulties in translating macro-level policy targets systematically into feasible production and operations objectives (Geels et al., 2015). To effectively transition from linear economies to circular resource efficient economies, robust indicators and frameworks, which facilitate the mapping of life-cycle impacts of resource production and consumption cycles in supply chains are required (Cucchiella et al., 2015; Huysman et al., 2015).

There are a number of useful conceptual frameworks on resource sustainability in the extant literature, mostly underpinned by theoretical perspectives like the resource-based view, Stakeholder theory (Sodhi, 2015), the Natural resource-based view (Shi et al., 2012), and the triple-bottom-line approach (Murali et al., 2015). However, there are still limited theory-based frameworks that address resource sustainability comprehensively from a supply chain perspective. This paper advances a framework for Supply Chain Resource Sustainability (SCRS) based on research experience and an extensive review of extant studies in response to calls for theory building and holistic conceptual frameworks (Pagell and Shevchenko, 2014). The study takes a conceptual theory building approach defined as the development of a set of concepts, with or without propositions, used to represent an event, object or process in an interpretative manner rather than a formal traditional research method, capturing the essence of the system under investigation (Meredith, 1993).

Regarding conceptual theory building in operations (and supply chain management) research, Meredith explained that:

“Unfortunately, there is a dearth of theories in OM, particularly theories, which are specific enough to allow the formulation of hypotheses, and propositions, which can be tested. Instead, OM researchers have used sophisticated and powerful theory-testing methods of hypothetical constructions of operating systems, which have little relation to reality and offer little or no utility to managers responsible for managing those systems in the real world. As a result:”... practitioners consider most OM research to be irrelevant.”
(p.3)

The conceptual modelling approach in this paper takes a ‘supply chain’ perspective (from pre- to post-production) of resource sustainability rather than firm perspective. Supply chains are complex adaptive systems (Carter et al., 2015 a) providing a realist and practical frame of

reference for assessing the interconnected environmental, economic, and social capital of resource inputs and outputs required for the production of goods or services. Secondly, since supply chains are sub-systems of production economies, managers could apply the SCRS framework to aid the translation of macro-level sustainability targets into actionable productions and operations objectives that are measurable and manageable. Drawing on extant theories and industry examples, the SCRS framework developed in this paper draws on five foundational premises (FPs) derived from the extant literature on sustainability; namely:

FP1: Scarcity is the ‘temporal outcome’ of ineffective identification, life-cycle mapping, and utilization of resources.

FP2: Supply chain resources comprise of environmental, economic, and social capital. By capturing and quantifying these streams of capital for critical cycles of inputs and outputs, researchers and practitioners can measure and manage SCRS more efficiently.

FP3: Identifying and managing the interconnectedness and overlaps in resource cycles optimizes the overall SCRS of specific product/service supply chains.

FP4: Contemporary business competition is shifting from firm-level focused management strategies to management strategies that are both: (a) supply-chain focused, and (b) resource sustainability focused.

FP5: Embedding the above foundational premises in predictive decision making improves supply chain resource forecasting, utilization, and conflict resolution decisions, and contributes towards translating macro-level sustainability targets into specific production and operations objectives.

The following section presents arguments to support the theorization for each of the foundational premises of SCRS proposed to arrive at a circular conceptual framework of SCRS. The SCRS framework outlines a series of steps based on the above premises and draws on the theory of constraints to facilitate the systematic application of the steps outlined for each FP in assessing the degree of embeddedness of SCRS. The framework serves as a guide to future studies on resource sustainability by providing indicative steps to facilitate the development of targeted strategies for SCRS and resource optimisation/efficiency based on the above premises. The framework also lends itself to practical application in terms of sustainable resource management and decision-making, and the accompanying pedagogical notes demonstrates examples from advanced manufacturing, retail and brewing industries with regards to current and potential future applications of the SCRS concept in industrial decision making and organizational processes.

2. Conceptual Development of the Circular SCRS Framework

2.1. Supply Chain Resource Sustainability

Every production process involves overlapping cycles of resource extraction, manufacturing, distribution, consumption, recycling, and reuse. These interactions within and across each cycle become even more complex with shifting production geographies and policy or regulatory requirements (Naor et al., 2015). Resource sustainability aims to optimize the economic benefits of production processes in a socially equitable way, without stretching the environment beyond its ecological limits (Sodhi, 2015). Recent studies have taken a systems approach to assess the impact of environmental, economic, and societal interactions on resource management in supply chains, which are essentially sub-systems of production macro economies characterised by intricate resource interdependencies (Cucchiella et al, 2015; Sodhi, 2015). From a systems perspective, supply chains would only be able to achieve equilibrium, sustainability, and steady growth by optimizing critical and overlapping resource flows across different tiers of suppliers and external stakeholders (Koh et al., 2013). Unlike open systems and mechanical systems that are capable of attaining the same final state through several linear paths (equifinality), supply chains are better conceptualized as 'complex adaptive systems', characterized as path dependent, self-organising, and sensitive to marginal changes in initial conditions (Carter et al., 2015 a, b; Choi et al., 2001).

Since supply chains are global, consisting of several interconnected chains operating across multiple boundaries and therefore it is impractical to isolate an absolute, linear, and independent resource chain (Tidy et al., 2016). Consequently, if resource management decisions are made independently, the sustainability of other connected resources could be affected, and this could have far-reaching environmental, economic, and social implications for supply chains and the wider society (Carter et al., 2015 a; Piercy and Rich, 2015). To arrive at a comprehensive framework for SCRS, this paper adopts a complex adaptive systems view of supply chains (see Carter et al., 2015 b), which characterises supply chains as path-dependent relationships among firms involving:

- a) Primary resource flows (inputs and outputs) among vertically or horizontally integrated focal firms.
- b) Secondary resource flows among the tiers of supplier and customers in the supply chain.
- c) Tertiary resource flows linking the supply chain to other supply chains within the broader supply network.

2.2. *Temporal Resource Scarcity*

There are three predominant perspectives in the literature on the nature and scope of resources, and despite similarities in these perspectives they differ significantly in the manner they conceptualize, capture, and report resource sustainability. One of the most common approaches is the triple bottom line, focusing on the economic social and environmental impact of resources and essentially reports these impacts as separate elements (Besiou and Van Wassenhove, 2015). The main shortcoming is that by reporting separate streams of capital policy makers and industrial players tend to emphasize the economic and environmental over social elements. Another notable perspective is the Triple-R approach (reduce, reuse and recycle) which was developed in Japan to achieve a sound material-cycle society (Takiguchi and Takemoto 2008). However, the main shortcoming is that it

conceptualizes resources from a material perspective, and although it accounts environmental impacts in its cyclic view it inadvertently ignores the social dimensions. The circular economy view is another perspective on resource sustainability where the emphasis is on cradle-to-cradle and close loop material resource flows (Yuan et al, 2006). This perspective significantly covers the main streams of resources, however there is unclear conceptual or policy-based definition of social sustainability implying a neglect of the social scope of resource sustainability. A critique of the predominant approaches to supply chain resource sustainability notes that there remain questions over whether it ‘pays’ to be sustainable, i.e. “Does being more sustainable than other unsustainable supply chains improve economic performance?” (Pagell and Shevchenko, 2014, pp 46-48). Supply chains often have to satisfy demands of stakeholders, such as NGOs, Governments, community groups who’s focus is not necessarily concerned about the economic performance of the firm, but on the overall impact on society or the environment, with SSCM literature offering limited insights into how to approach environmental or social concerns (Pagell and Shevchenko, 2014).

In line with the above arguments, we adopt a circular view of supply chain resources, but we augment this view by incorporating five foundational propositions to account for the interconnected impacts of these separate streams of resources (economic, environmental, and societal capital) on the overall resources sustainability of supply chains. Drawing on a framework illustrated in OECD Green Growth (2014) document, we view supply chain resource sustainability in terms of four overarching streams of resources (Koh et al, 2016):

- 1) *Carbon and other emissions related resources*, expressed in terms of the amount of production-related emissions (in Kgs) required to generate 1 \$ of GDP.
- 2) *Energy resources*, operationalised as the amount of energy, (in kt_{oe}) required to generate \$1 of GDP.
- 3) *Material resources*, expressed as the amount of non-energy resources, (in Kgs), required to generate \$1 of GDP
- 4) *Social resources*, expressed as the aggregate value-added to key stakeholders within a social network, derived from both production and consumption activities (Chen and Hung, 2014). The sustainability of social resources could be quantified using measures from the Human Sustainability Development Indices (HSDI) such as life expectancy, education, disposable income, personal growth, security, well-being, and emissions per capita (See Togtokh 2011).

Our conceptualisation of “circularity” in the framework builds on the circular economy perspective but incorporates a clear definition of social sustainability. Thus, taking a complex adaptive systems perspective, we conceive supply chain resources *as* everything within the scope of a given supply chain - tangible and intangible, direct and indirect, natural and man-made, human and machines - which adds quantifiable value to supply chains and influences decision making. Furthermore, in line with the Brundtland 1987 definition of sustainable development, SCRS is defined as *the effective use of all interconnected supply chain resources for economic, social, and environmental capital generation, while accounting for the long-term environmental, economic, and socio-political impact of production activities*. Thus, sustainable resource practices must be economically viable but socially and environmentally responsible to stakeholders (Bai et al., 2012; Hassini et al., 2012).

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4 The classical 'Utopian' view of resources held that natural resources had no long-term limit
5 in terms of quantity, and were not subject to changes in quality (Jayasuriya, 2015). Following
6 the Second World War, classical economists like Malthus, Mill, and Ricardo began to put
7 forward arguments that the total output of natural resources would eventually reach a steady
8 state of non-growth, and eventually impose an upper limit to economic growth and social
9 welfare (Washington, 2015). This influenced the development of theories like transaction
10 cost theory, resource-based view, and natural resource-based view, essentially drawing on the
11 economic premise of resource scarcity as a principal driver of efficiency and competition
12 (Barbier, 2013; Simon, 1998). The 'Conservation Movement' in the United States, formed in
13 response to a 1662 publication titled 'Sylva' by John Evelyn, was established to address the
14 perceived concerns over natural resource scarcity from a global sustainability policy
15 viewpoint (Jayasuriya, 2015). A modern version of this movement took the form of a national
16 agenda in the 1970s following the establishment of the Environmental Protection Agency.
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21 It is unquestionable that natural resource production is in a steady state of decline, especially
22 relative to other tangible resources (Wan et al. 2015, Washington, 2015). As far back as the
23 1980's, Slade (1982) noted that, "if scarcity is measured by relative prices, the evidence
24 indicates that non-renewable natural-resource commodities are becoming scarce."
25 Consequently, most frameworks on resource sustainability tend to adopt this scarcity
26 perspective, focusing on reducing resource exploitation, waste, and emissions. However,
27 evidence suggest that there has been no significant rise in the real cost, or relative prices of
28 natural resources over time (Peet and Hartwick, 2015, Rebelo, 1990, Simon, 1998). One
29 explanation is that as intangible resources such as knowledge increase exponentially,
30 environmental resource scanning capabilities also improve (Fabbe-Costes et al., 2014).
31 Therefore, it may be misleading to suggest that 'accurate inventories' of natural resources
32 could be determined, because knowledge and other intangible resources contribute to the
33 discovery and development of supplementary or alternative resources in response to growing
34 demand (Simon, 1998). According to Brobst (2013, P.115): "*Reserves and resources are part
35 of a dynamic system and they cannot be inventoried like cans of tomatoes on a grocer's shelf.
36 New scientific discoveries, new technology, and new commercial demands or restrictions are
37 constantly affecting amounts of reserves and resources. Reserves and resources do not exist
38 until commercial demand puts a value on a material in the market*"
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45 The Jevons Paradox put forward by Stanley Jevons in 1965 regarding fossil fuel utilization,
46 suggested that reducing consumption or increasing efficiency within one system in isolation,
47 often results in increased consumption or new inefficiencies in related systems (Polimeni et
48 al., 2015). Some have argued that advancements in food production following the Green
49 Revolution inadvertently led to population growth and the social consequence of soaring
50 global hunger (Buckle, 2015). Nonetheless, advocating for lower resource consumption also
51 has its flaws, as frugal consumption creates a form of short-term resource efficiency as an
52 adaptation to scarcity, which may not be sustainable in terms of environmental, economic,
53 and social capital (Brobst, 2013). Although reducing consumption is a worthwhile aim in
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3 itself, ignoring other intangible inputs and outputs, the interconnected resource cycles across
4 different supply chain tiers, and the effect of boundary-spanning suppliers leads to temporal
5 resource scarcity. From an efficiency perspective, the aim of sustainability is to efficiently
6 and effectively identify, map, utilize, recycle, and reuse all the relevant resource inputs and
7 outputs dispersed across supply chains, whilst a 'resource scarcity' perspective emphasizes
8 lower consumption and reduced exploitation of natural resources (Peet and Hartwich, 2015).
9 The latter view appears rather unrealistic in today's global economy, given added
10 complexities of globalization, and the rising costs and consumption of energy and natural
11 resources.
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15 From production and operations perspectives scarcity is better conceptualized as a 'temporal'
16 phenomenon resulting from the ineffective mapping, identification, and utilization of specific
17 resource cycles, where SCRS in contemporary production operations requires estimates of all
18 relevant cycles of tangible and intangible supply chain inputs and outputs to inform decision-
19 making. By tracing and optimizing specific resource cycles, decision makers can identify
20 consumption, emission, and waste hotspots in their supply chains and reduce overall temporal
21 scarcity. Researchers and managers need a combination of input-output analyses, and life-
22 cycle approaches to quantify or monetize the cycles of inputs and outputs for SCRS reporting
23 and efficient decision making in a transdisciplinary effort. While it is evident that 'known
24 reserves' of oil and gas are in decline, technological advancement and R&D collaborations in
25 oil and gas supply chains, have improved overall capabilities in recovering and maintaining
26 hydrocarbon reservoirs. There is clearly room for improvement through life-cycle analysis of
27 specific resource paths, but it is noteworthy that some International Oil Companies (IOCs)
28 have made big strides and investments in discovering and producing energy through
29 unconventional reserves using novel technologies not previously accessible (Chima, 2011).
30 The Jevons paradox cited earlier still applies here; however, the life-cycle and input-output
31 approach to resource management from a supply chain perspective would create cleaner and
32 more sustainable resource paths and diminish temporal scarcity. Accordingly, it is theorized
33 that for supply chain resources:
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39 *FPI: Scarcity is the 'temporal outcome' of ineffective identification, life-cycle*
40 *mapping, and utilization of resources.*
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44 2.3. The Scope of Resources: Assessing Social, Economic, and Environmental Capital

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46 There are three broad streams of capital generated in the transformation of raw material to
47 finished products in value chains, namely:

- 48 1. Economic capital – such as financial assets.
- 49 2. Environmental capital– made up of *natural capital*; like renewable and non-renewable
50 natural resources, and *produced capital*; meaning all fixed assets used in production
51 which are not direct outputs e.g. tools, machines, and buildings.
- 52 3. Social capital – made up of *human capital*; like health, knowledge, skills, motivation
53 and labour for productive work, and *societal capital* used in maintaining human capital
54 e.g. families, communities, businesses, and unions (Carey et al., 2011).
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4 As argued earlier, it is necessary to quantify and report all the streams of capital associated
5 with the predominant cycles of inputs and outputs in production supply chain to capture
6 SCRS. Most companies report their social and environmental sustainability through corporate
7 social responsibility (CSR) (Freeman and Hasnaoui, 2011). Recent definitions of CSR (see
8 Sodhi et al., 2015) have remained consistent with Bowen's (1953 p.6) definition as '*the*
9 *obligations of businessmen to pursue those policies, to make those decisions, or to follow*
10 *those lines of action which are desirable in terms of the objectives or values of our society*'.
11 To date, supply chain level CSR has remained more or less dependent on how focal firms
12 conceive the societal and environmental value of different operations at different locations
13 across supply chains (Freeman and Hasnaoui, 2011, Sodhi, 2015). Studies have measured the
14 economic capital of resources in terms of the costs and benefits of different sourcing,
15 procurement, manufacturing, and recycling/reuse practices (Baumgärtner and Quaas, 2010).
16 The environmental capital of resources focuses on the ecological impact of production inputs
17 and outputs such as energy and water consumption, gas emissions, biodiversity protection,
18 waste disposal, and recycling (Longoni and Cagliano, 2015). Social capital, on the other
19 hand, deals with issues like human rights, work practices, public policy, and consumer health
20 and safety linked to cycles of resource inputs and outputs (Sodhi, 2015).
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26 2.3.1 Assessing the Environmental and Ecological Capital of Resources

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28 In addition to the direct impact of critical raw materials in production supply chains,
29 industrial ecology and ecological planning also have significant impacts on SCRS (Galli, et
30 al., 2012; Longoni and Cagliano, 2015; Naor et al., 2015). Industrial ecology considers the
31 impact of industrial processes on the environment, people, and other forms of life (Linton et
32 al., 2007). Ecological planning examines how supply chains map their resource cycles to
33 minimize wasteful consumption and emissions as well as second life for by-products
34 (Acquaye et al., 2014). At country/regional levels, researchers have applied direct component
35 approaches like ecological footprinting, and life-cycle analysis to run cost-benefit
36 investigations into the impact of resource inputs and outputs and to develop area-based
37 indicators of sustainability (Bai et al., 2012). Since supply chains are sub-units of the
38 industrial macro-economy, similar approaches are required to estimate the environmental and
39 socio-ecological aspect of SCRS. To this end, hybrid life-cycle and input-output approaches
40 like the 'Supply Chain Environmental Analysis Tool' (SCEnAT) have been developed for
41 mapping emission 'hotspots' in supply chains (Koh et al., 2013). This technique incorporates
42 a decision support interface, and updated versions of this methodology like SCEnAT+ now
43 include life-cycle costing, supply chain benchmarking against industry standards, and
44 ecological foot printing for land use, water, energy and product/process toxicity (Acquaye et
45 al., 2012) and SCEnATi amalgamated with big data analytics, business intelligence and
46 integrated resource efficiency index (Koh et al., 2016). Such approaches are useful for
47 detailed impact assessment of resource use beyond the scope of carbon emissions in supply
48 chains. The impact of remanufacturing, recycling, and refurbishment cannot be ignored
49 because they account for carbon leakage which occurs when supply chain integrators move
50 their production processes to countries with weak sustainability policies (Acquaye et al.,
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2012; Meunier et al., 2014). Sub-national input-output data like the OECD Green Growth indicators and the Global Reporting Initiative (GRI) indices (OECD, 2014) could be used to benchmark and assign environmental impact values to supply chain operations in different locations for predictive decision making, management, and reporting of resource sustainability (Cucchiella et al., 2015).

2.3.2 Assessing the Social Capital of Resources

Focal companies and supply chain integrators use of codes of conduct, voluntary certifications, and aggregated indexes like the Global Reporting Initiative (GRI), to benchmark and report corporate environmental and social performance. The GRI (2013) defined social sustainability as “the impacts the organization has on the social systems within which it operates”. It further outlines some social sustainability indicators like labour practices, human rights, health, product responsibility, taxes, and anti-corruption practices among others. Most CSR reports usually include such qualitative measures, however, a broader range of social capital indicators are required (Mota et al., 2014). The monitoring and reporting of social capital in supply chains has received some attentions following recent disasters like the collapse of the Rana Plaza factory in Bangladesh, and the ‘human trafficking’ scandal involving employers in the Thai shrimp industry who supply some of the world’s largest retail chains like Walmart, Tesco and Morrisons. Regarding the latter, LeBaron and Lister (2015 p.905) noted that ‘retailers are, in fact, auditing only small portions of supply chains, omitting the portions of supply chains where labour and environmental abuse are most likely to take place.’

Researchers could use macro-level measures like the Human Development Index (HDI), the Human Sustainability Development Index (HSDI), and the OECD Green Growth Indicators to develop quantifiable measures of social capital for estimating SCRS (Bravo, 2014; OECD, 2014; Koh et al, 2016). Although there are scalability issues with these macro-level measures, such approaches could enable supply chain integrators like the big retailers cited above, to tackle their resource efficiency. Hybrid life-cycle and input-output methodologies enable the assessment of resource practices associated with specific products, in order to optimize supply chains from a bottom-up (specific resource cycles) and top-down (aggregate supply resource cycles) perspectives.

2.3.3 Assessing the Economic Capital of Resources

The Global Reporting Initiative outlines several indicators of Economic capital such as profit/loss, turnover, market presence, and the indirect economic impacts of Human resource management and procurement practices (GRI, 2013). Studies have shown that firms that develop and measure the environmental and social capital of their resource practices enjoy associated economic benefits as well (Rao and Holt, 2005; Parmigiani et al., 2011). Thus, measuring economic capital together with the social and environmental capital of critical supply chain inputs and outputs in a single SCRS framework is necessary to improve supply chain resource practices, reporting, and accountability. Although the implementation of

environmental and social sustainability usually attracts short-term costs, making resource decisions based on cost-benefit analysis and trade-offs involving all streams of capital linked to resource practices is more sustainable and competitive in the long-term (Aflaki et al., 2013; Baumgärtner and Quaas, 2010; Porteous et al., 2015). Some firms include the three dimensions of resource capital in their sustainability reports, however the triple bottom line approach taken often implies that social and environmental capital are reported independently, thereby distinguishing ‘sustainability objectives’ from the ‘business objectives’ of supply chains (Nidumolu et al., 2009, Besiou and Van Wassenhove, 2015). Managers and researchers could now draw on the SCRS framework to develop a clear picture of the aggregate socio-economic and environmental capital associated with vital supply chain inputs and outputs to inform decision making for supply chain functions like purchasing, manufacturing, recycling, R&D, and logistics. Based on the preceding arguments, we theorize that:

FP2: Supply chain resources comprise of environmental, economic, and social capital. By capturing and quantifying these streams of capital for critical cycles of inputs and outputs, researchers and practitioners can measure and manage SCRS more efficiently.

2.4. Managing the interconnectedness of Resource Cycles from Upstream to Downstream of Supply Chains

Horizontal or vertical integration creates interconnected cycles of inputs and outputs across supply chain tiers, from energy through work-in-progress inventory, to finished products, waste, by-products, and emissions. The combined resource capital of suppliers-environmental, economic, and societal- can have significant long-term impacts on entire supply chains. This is further complicated when such suppliers are boundary spanning across industries. For instance, the implementation of the Ethical Trading Initiative and Business Social Compliance Initiative (BSCI) by ready-made garments (RMG) buyers transferred the “child labour” problem from RMG suppliers to less regulated but boundary-spanning industries like logistics and construction in Bangladesh (Huq et al., 2014). Global outsourcing implies that supply chain players overlap different markets and national/supra-national regulatory environments (Coe et al., 2008), requiring a multi-dimensional life-cycle approach to resource sustainability accounting to capture the complex resource circuitries of global supply chains (Koh et al., 2012; Parmigiani et al., 2011). Choi et al. (2001) outlined three factors to consider when making operations decision in complex adaptive systems with several interdependent links. Firstly, although several interlinked resource cycles exist, a few of them have a crosscutting effect on the entire system. Secondly, significant and long-term system changes result from collaborative actions and decisions of agents, and thirdly, when agents focus on individual goals, system-wide targets like resource efficiency and sustainability are difficult to monitor, measure or improve (Carter et al., 2015a,b; Montabon et al., 2015).

The resource sustainability of base industries like mining and oil and gas have an impact on the SCRS of almost every supply chain. Most oil and gas companies use multiple

sophisticated systems to monitor their internal sustainability performance. For instance, BP reported that it carries out screening and life-cycle environmental impact assessments from the planning stages and throughout the construction, operations, and decommissioning of projects (BP, 2014). However, regarding GHG reporting, a recent longitudinal study carried out in the industry showed that between 1998 and 2010, the quality of GHG reporting in the industry in terms of “search”, “experience” or “credence” had not improved (Comyns and Figge, 2015). This study argues that estimating the resource capital for inter-regional and inter-scalar resource cycles in production supply chains provides a more accurate interpretation of the resource sustainability within in, and it is theorized that:

FP3: Identifying and managing the interconnectedness and overlaps in resource cycles optimizes the overall SCRS of specific product/service supply chains.

2.5. Sustainable Supply Chain Competition as the New Frontier

Supply chain integrators account for resource sustainability through voluntary ecolabels, ISO14024 guidelines, and standards like Fairtrade in upstream agricultural supply chains (Gualandris et al., 2015). However, most standards are generic and may not sufficiently cover emergent sustainability issues; particularly in poorly regulated parts of a supply chain (Pagell and Shevchenko, 2014). In addition, CSR sometimes narrows down the scope of sustainability that is monitored and reported by focal firms. Gualandris et al., (2015) argued that resource sustainability should address varying stakeholder concerns, but “not necessarily all equally”. They further argued that in order to be useful; sustainability reporting must reflect the interrelated dimensions of accountability like inclusivity, scope, and disclosure. Using the case of Starbucks and Unilever, they noted that both companies were working with their upstream suppliers to identify relevant sustainability issues and measures in their supply chains. However, in keeping with their CSR focus, Starbucks and Unilever do not collaborate to the same degree with stakeholders on other sustainability issues such as recycling, waste management, and energy accountability. Nonetheless, a sustainability challenge occurring outside a supply chain, CSR focus can be costly. To remain competitive, supply chains require robust life-cycle and input-output techniques for identifying potential challenges and ‘focusing’ their sustainability priorities. In systems optimization research, the Theory of Constraints (TOC) states that each system contains a few critical internal and external constraints, which can alter the entire system performance (Puche et al., 2016). In this context, SCRS constraints could be supply chain practices in remote parts that prevent the entire system from achieving expected or desired sustainability targets.

The scope for supply chain competition based on price or product uniqueness is rather rare today, because competitors across different industries share similar technologies, processes, and suppliers (Porter and Kramer, 2006; Touboullic and Walker, 2015; Luzzini, et al., 2015). Recent studies have shown that supply chains with a few strong and strategic collaborations with strategic suppliers achieve incremental eco-innovations, while those with weaker ties to multiple suppliers make radical eco-innovations by bridging the ‘structural holes’ or knowledge gaps created by boundary spanning suppliers (Roscoe et al., 2016). Studies have shown that by mapping key supply chain resources to their points of origin, decision makers

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3 can better identify and replace inefficient resource practices with more sustainable ones
4 (Cucchiella et al., 2015). With increased globalisation and virtualisation of supply chains due
5 to advances in technology and outsourcing, competition has gradually shifted from firm-level
6 resource management strategies to supply-chain focused resource sustainability strategies.
7 Many supply chains now use life-cycle approaches, including the ‘total cost of ownership’
8 cost appraisal method for supplier selection, purchasing, and resource management decisions
9 and improved competitiveness (Linton et al., 2007; Erol et al., 2011; Koh et al., 2011).
10 Consequently, a multi-faceted approach to SCRS is necessary, partly, to optimize resource
11 management decisions and practices - including outsourced operations, but increasingly as a
12 proactive supply chain strategy for improving competitive advantage (Engert et al., 2016;
13 Seuring, 2013; Obayi et al., 2017). The SCRS approach would facilitate decision makers and
14 researchers in the examination of the main streams of capital for all value adding processes in
15 different scalar levels of the supply chain. To remain competitive, SCRS monitoring and
16 management in production supply chains should account for the circularity of resource flows,
17 and must be performed iteratively and collaboratively with key supply chain players. As
18 such, it is theorized that:
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23 ***FP4:** Contemporary business competition is shifting from firm-level focused*
24 *management strategies to management strategies that are both: (a) supply-chain*
25 *focused, and (b) resource sustainability focused.*
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28 2.6. Embedding Supply Chain Resource Sustainability in Predictive Decision Making

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30 Many supply chains use production-planning tools like Enterprise Resource Planning (ERP)
31 and ERPII to aid resource-related decisions (Hellweg and Canals, 2014, Ketikidis et al.,
32 2008). Such tools could generate a reasonable amount of data on resource practices with the
33 help of cloud computing and advanced data mining techniques. Nevertheless, isolating
34 suitable indicators for SCRS is challenging due to poor visibility and integrated IT platforms
35 in remote upstream supply nodes where potentially serious resource sustainability challenges
36 could exist (Shaw et al., 2010). Additional challenges include poor oversight and lack of
37 standardized supply chain ethical auditing persist (LeBaron and Lister 2015), coupled with
38 the need to address big data management, conflicting management strategies and data
39 confidentiality issues (Hassini et al. 2012). Bai et al. (2012) supported the use of data
40 reduction techniques like factor analysis to streamline the potential measures for the latent
41 aspects of sustainability associated with the resource utilization decisions and practices of
42 supply chains. Furthermore, ERP data could be analysed using the hybrid LCA techniques
43 for evidence-based resource sustainability decisions in supply chains. Researchers and
44 practitioners could use sub-national input-output data as well as indicators from the Human
45 Sustainability Development Index (HSDI) and the OECD Green Growth. There are still
46 challenges in terms of the scalability and granularity of these macro-level measures (Koh et
47 al., 2013), nonetheless the emergent SCRS framework based on the preceding premises
48 would improve predictive resource efficiency and decision-making. Accordingly, the last
49 theorized premise for SCRS states that:
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FP5: Embedding all foundational premises of SCRS in predictive decision making improves supply chain resource forecasting, utilization, and conflict resolution decisions, and contributes towards translating macro-level sustainability targets into specific production and operations objectives.

Figure 1 shows the schematic of the proposed SCRS framework. In the next section, some criteria for assessing the embeddedness of the theorized foundational premises of SCRS are itemised in Table 1 and discussed. In addition, the potential decision support application of the framework for SCRS measurement and management in production supply chains is illustrated, drawing on the Theory of Constraints.

[Insert Figure 1 here]

3.0 Decision Support Methodology for Supply Chain Resource Sustainability

Kahneman (2003) argued that:

“Narrow frames generally reflect the structure of environment in which decisions are made. The choices that people face arise one at a time, and the principle of passive acceptance suggests that they will be considered as they arise. The problem at hand and the immediate consequences of the choice will be far more accessible than all other considerations, and as a result decision problems will be framed far more narrowly than the rational model assumes.” (p. 1460)

Earlier, we defined supply chains as complex adaptive systems, subject to the theory of constraints, implying few critical internal or external constraints could alter the performance of the entire system. Using a series of ‘focusing steps’ can isolate and manage constraints to improve system outcomes (Puche et al., 2016) continuously. In a hypothetical supply chain without constraints, sustainability throughput (or goals achieved per unit time) would be infinite. However, in practice, constraints like inefficient resource/process mapping, and poor identification of connected input-output cycles, leads to temporal resource scarcity. These steps include:

- (a) *Identify resource sustainability constraints*, which lead to temporal resource scarcity (e.g. wasteful or poor resource management practices etc.)
- (b) *Exploit resource sustainability constraint* to isolate and minimize their effect on the entire supply chain.
- (c) *Subordinate everything else to the resource sustainability constraint*, to ensure that all policies and practices that hamper resource sustainability are constrained at specific supply chain ‘hotspots’.

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3 (d) *Elevate and invest in improving the constraint* through process redesign or supply chain
4 reengineering. Many supply chains benchmark and invest in sustainability initiatives
5 without first identifying specific resource constraints in their supply chains.
6
7 (e) *Manage areas of inertia or 'resistance to change'*, which could pose new constraints to
8 SCRS. This requires a circular perspective to SCRS, and it broadens the otherwise
9 narrow frame used in most supply chains for predictive decision-making regarding
10 resource utilization and management.
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15 [Insert Table 1 here]

16 Table 1 sets out the SCRS criteria drawn from the foundational premises of SCRS articulated
17 in preceding sections. The columns represent each premise in the SCRS framework, whilst
18 the rows outline different levels of application or degree of embeddedness of the SCRS
19 criteria in decision-making (one=lowest, five=highest). As shown in Figure 1, following an
20 assessment of the resource portfolio of a given supply chain, optimisation attempts could be
21 made to overcome temporal resource scarcity. This would require making the right
22 investments to facilitate continuous progress from mere commitments to the minimisation of
23 waste and virgin resource utilisation to a more collaborative, input-output, and life-cycle
24 management approach. Likewise, for the second FP, the criteria developed could be used to
25 inform advancements from recognising resource capital towards a collaborative approach to
26 quantification and reporting. Once the desired level of quantification and reporting is
27 attained, it becomes relatively easier to map the relevant and interconnected streams of
28 resources. Managers can then develop collaborative strategies with partners to support joint
29 resource utilisation and management decisions. The fourth FP provides criteria to enable
30 managers benchmark their SCRS competitiveness, after adequate quantification and
31 mapping. Subsequently, unified standards for SCRS can be developed to facilitate
32 assessments of the embeddedness of SCRS considerations in resource management decision-
33 making, from utilisation and allocation to supplier selection and supply chain re-
34 configuration. Practical applications of this framework are provided in the pedagogical notes
35 attached to this paper.
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42 At the lowest level of managing temporal resource scarcity, focal firms tend to emphasize
43 consumption reduction (minimizing emissions, water, energy, etc.) but pay little attention to
44 the interconnected inputs and outputs across tiers of suppliers (see Table 1 FP1:1). At the
45 next level, supply chain integrators commit to waste management, recycling, and reuse of
46 resources (FP1:2). The subsequent levels advance progressively from supply chains that
47 adopt collaborative resource management strategies with SC partners based on industry
48 benchmarks (FP1:3), to those that invest in R&D based on benchmarks and other evidence-
49 based management techniques like LCA and input-output analysis to improve the resource
50 efficiency at key supply chain hotspots (FP1:4). At the highest level of managing temporal
51 scarcity, supply chains advance their R&D and resource management strategies to cover all
52 critical tiers of resources from upstream to downstream (FP1:5).
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Likewise, for the second foundational premise, supply chains at the lowest level of resource sustainability recognize the impact of social (FP2a:1), environmental (FP2b:1), and economic (FP2c:1) capital, but resource sustainability reporting is absent or minimal at this stage (Montabon et al., 2007). The next level is characterised by supply chains where the focal firm or supply chain integrator is primarily responsible for measuring and reporting certain aspects of environmental (FP2a:2), societal (FP2b:2), and economic (FP2c:2) capital of direct resource practices based on international or industry standards. At this level, nodes with critical sustainability constraints could be inadvertently or deliberately misreported, mismanaged, or ignored (LeBaron and Lister, 2015). The recent "diesel dupe" case involving the automaker Volkswagen, provides an instructive example. The Environmental Protection Agency (EPA), recently found that the manufacturer of the Audi A3, Jetta, Beetle, Golf and Passat cars had fit a cheat software in nearly 11 million vehicles worldwide, to monitor and cheat on carbon emission reporting (EPA, 2016). At intermediate levels of SCRS, supply chain actors progress from independently quantifying and reporting their resource capital (FP2:3), to a more standardized and systematic approach to monetising/quantifying resource capital of resource collaboratively (FP2:4). At the highest level of resource capital accounting, SCRS reporting is integrated, decision-making is collaborative, and resource management depends on comparative resource capital information (F2:5).

Regarding the interconnectedness of supply chain resources across different tiers, focal firms recognize the importance of information sharing and collaboration with first tier suppliers at low levels of resource sustainability. They adopt tools like ERP (see FP3:1). Advanced supply chains make use of sophisticated tools for information sharing, planning and forecasting with suppliers as an initial step towards systematic resource cycle mapping like ERP II, and Collaborative Planning, Forecasting and Replenishment (CPFR). For higher levels of interconnected resource sustainability, supply chain players need to collaboratively identify and map the impact of the production practices of primary suppliers and other stakeholders, using lifecycle and input-output approaches to identify and isolate system constraints (FP3:3). At the next stage of SCRS, managers adopt standardized life-cycle and input-output costing and analysis alongside SC collaborative tools, strategies, certifications, and benchmarks to assess critical resource cycles and to develop a clear and feasible sustainability strategy.

Many focal firms appreciate the competitive benefits of resource sustainability but are unable to harness the full potential to their advantage due to the narrowly framed methodologies, certifications and eco-labelling regulations. To harness the potential competitive advantage, firms at lower levels of SCRS use interconnected resource capital information and practices in a reactive manner for problem solving. Since outsourcing has increased the number of global and boundary spanning suppliers, SCRS can generate a competitive advantage for supply chains who work collaboratively with different tiers of suppliers to develop sustainability indicators and diminish the information and knowledge asymmetries resulting from structural holes. In so doing, decision makers can isolate remote system constraints and make targeted investments in SCRS practices and strategies to mitigate emerging resource challenges (FP4). FP5 provides the integrated platform to consider FP1-FP4 decisions in a

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3 circular approach and link strategic macro level decision to operational micro level decision.
4 This circularity is paramount in the SCRS framework due to the dynamic and evolving nature
5 of critical resources (constraints). By assessing resource sustainability against the five
6 theoretical premises, supply chains managers can develop a clearer profile of the SCRS of
7 critical resource cycles in their supply chains. The criteria in Table 1 could serve as focusing
8 steps for assessing resource sustainability against the proposed foundational premises to
9 develop a holistic perspective on SCRS in supply chains. Genovese et al. (2015) in a recent
10 case study exploring the transition of supply chains towards a circular economy identified
11 some of the predominant practical constraints to SCRS, including the fragility of the current
12 socio-political and relational mechanisms for enabling and enacting such sustainability
13 frameworks in supply chains; and the inability to anticipate the scope of influence of
14 sustainability initiatives on market dynamics, supply chain configuration, and buyer-supplier
15 relational dynamics. Whilst this framework does not claim to address all constraints, it
16 provides a methodology based on the theory of constraints for exploring different iterations
17 of SCRS that could result from pursuing the five foundational premises in varying degrees, to
18 account for the most pressing constraints in specific supply chains
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23 **4.0. Conclusions**

24
25 This paper adopted a conceptual theory building approach in an attempt to unify the
26 fragmented research on resource sustainability in supply chains through five foundational
27 premises of SCRS. This SCRS framework was developed to facilitate multi-scalar
28 assessments of resource sustainability in production supply chains. Theoretical arguments
29 were presented to support the claim that resource scarcity is a temporal phenomenon that can
30 be better managed by identifying, mapping, and appraising the interconnected resource cycles
31 within supply chains. Furthermore, it was argued that by capturing and quantifying the
32 different streams of resource capital of critical supply chain inputs and outputs (including by-
33 products and emissions), researchers and practitioners can measure and manage SCRS more
34 efficiently. The paper supported this claim by making references to recent studies that have
35 adopted hybrid life-cycle and input-output techniques to quantify and map the different
36 scopes of supply chain resources (emission, material, energy and social capital), with
37 valuable insights for production optimisation and decision-making.
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43 In addition to quantifying critical resources, another key foundational premise for SCRS
44 expounded in this paper is that by identifying and accounting for the interconnected and
45 overlapping resource cycles within a supply chain in resource management decisions,
46 managers can improve the SCRS for specified resources within a supply chain. Finally, by
47 drawing on principles from the theory of constraints, the paper proposed a methodology for
48 embedding all foundational premises of SCRS in predictive decision-making, outlining
49 different levels of SCRS in line with each premise. These ideas underlying SCRS are evident
50 in practical applications of the SCRS concept to Advanced Manufacturing, Retail and
51 Brewing industries (see attached pedagogical notes). Here LCA techniques have been applied
52 to quantify dependency on critical resources (e.g. rare-earth materials in advanced
53 manufacturing), and quantification and target setting of environmental, social, and economic
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3 efficiencies and standards placed on suppliers within supply chains. Supply chain
4 collaboration and competition is already implicit across industrial settings, highlighted by
5 overlapping supply chain collaboration in retail industries and the competitive advantages
6 that arise from more resource efficient and sustainable supply chain practices that translate to
7 lower prices and market opportunities for consumers.
8

9
10 The circular approach to SCRS proposed in this framework incorporates decision rules based
11 on the theory of constraints and thus, serves as an exemplar that could facilitate managers'
12 ability to make targeted improvements towards SCRS, and could contribute to the translation
13 of macro-level sustainability targets into specific production and operations objectives. It
14 could also serve a template for researchers to evaluate empirically, the resource sustainability
15 for specific inputs or outputs in supply chains. For practitioners, the framework provides a
16 useful decision support methodology for assessing SCRS.
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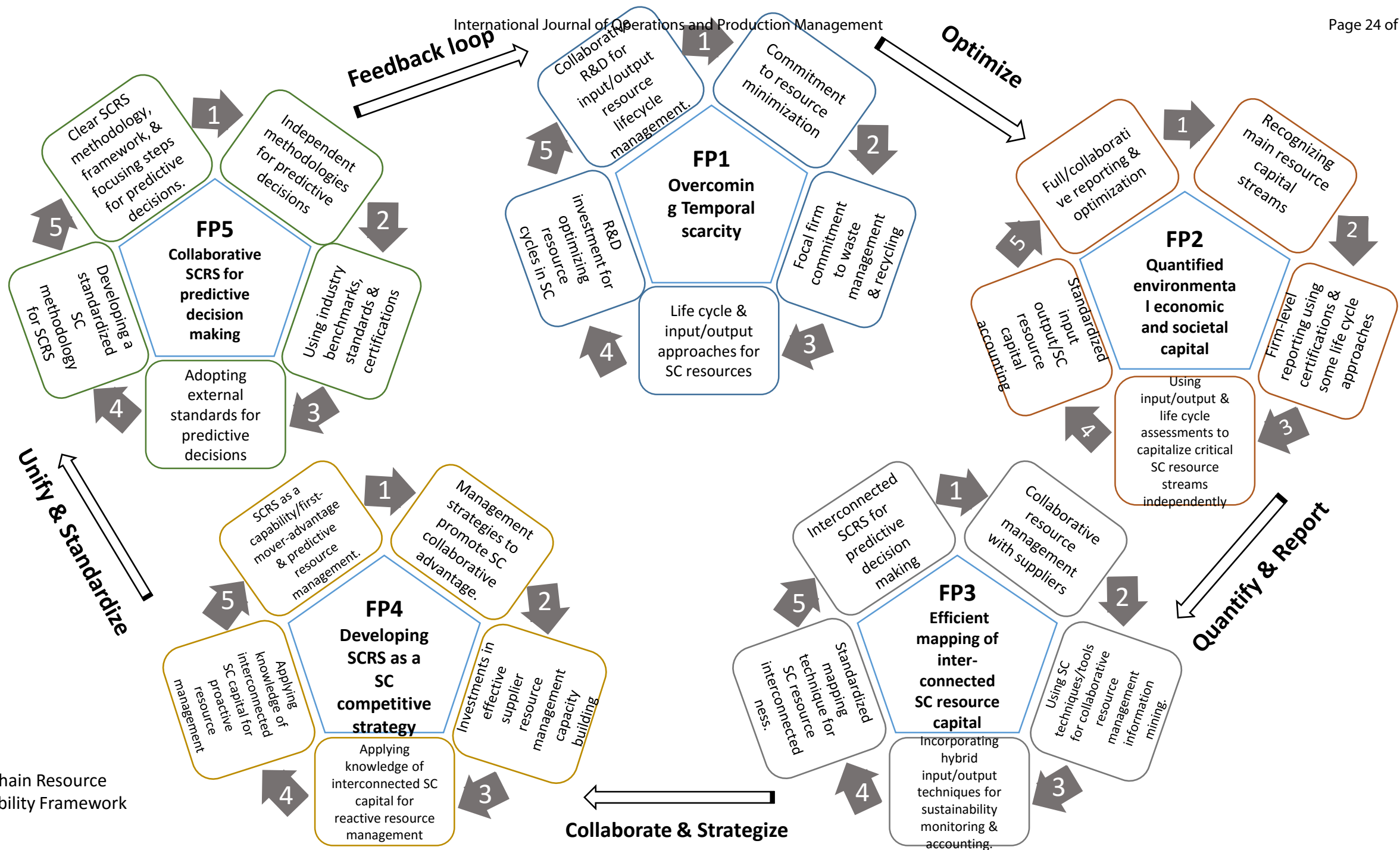


Figure 1:
Supply Chain Resource
Sustainability Framework

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Table 1. Supply Chain Resource Sustainability Criteria

| | FP1 – Temporal Resource Scarcity | FP2a - Environment Resources Capital | FP2b – Social Resources Capital | FP2c - Economic Resources Capital | FP3 – Managing Interconnected cycles of resources in SCs | FP4 – SC Resource Sustainability as a Competitive Strategy | FP5 – Predictive Decision Making using SCRS |
|---|---|---|--|---|---|---|---|
| 1 | Focal firms/integrators are committed to resource minimization (e.g. emissions, water, and energy). Poor attention to secondary input and output resource cycles. | Focal firms/integrators recognize the main environmental of resource management practices and business operations (e.g. emissions) with minimal reporting. | Focal firms/integrators recognize the main social impact of resource management practices and business operations (e.g. staff development) with minimal reporting. | Focal firms/integrators recognize the main economic impacts of resource management practices and business operations (e.g. turnover, profit, market presence) | Focal firms/integrators acknowledge the impact of collaboration with suppliers on resource sustainability. | Acknowledgement of suppliers as mechanism to gain competitive advantages. | SC players with independent methodologies for monitoring and auditing resource practices. |
| 2 | Commitment to waste management, recycling, etc. in addition to resource minimization. | Reporting the environmental impact of business operations (e.g. carbon emissions, pollutant generation) by SC integrators. | Reporting the social and ethical impact of organisational operations (e.g. anti-corruption, human rights) by SC integrators. | Reporting the economic impact of organisational operations by SC integrators. | Use of SC tools for information sharing, planning and forecasting with suppliers to enable process and resource mapping (e.g. ERP, ERPII, CPM) | Investment in improved supplier capacity, information processing and sharing with little attention to supplier resource sustainability. | SC players adopting industry benchmarks and external monitoring/audit criteria for resource sustainability. |
| 3 | Incorporating resource reuse and recycling management strategy with SC partners based on industry benchmarks. | Attempts by focal firms and suppliers to independently monetise/quantify and report the environmental capital of resource production and consumption | Attempts by focal firms and suppliers to independently monetise/quantify and report the social and ethical capital of resource production and consumption. | Attempts by focal firms and suppliers to independently monetise/quantify and report the economic capital of resource production and consumption. | Attempts to use life-cycle and input-output costing and analysis alongside SC collaborative tools and strategies for critical nodes in the SC. | Recognizing the role of SCRS, and using information about the social, environmental, and economic capital of interconnected resource cycles and practices in a reactive manner for problem solving. | Using externally approved methodologies for monitoring of SC resource management practices. |
| 4 | Investing in R&D to improve production efficiency and second-life channels for primary and secondary inputs and outputs based on evidence based knowledge. | Establish a standardized approach to monetise/quantify the environmental capital of resource production and consumption collaboratively by key SC players. | Establish a standardized approach to monetise/quantify the social/ethical capital of resource production and consumption collaboratively by key SC players. | Establish a standardized approach to monetise/quantify the economic capital of resource production and consumption collaboratively by key SC players. | Engaging stakeholders to formulate a SCRS strategy that builds upon standardized life cycle and input-output costing and analysis alongside SC collaborative tools and strategies for all critical resource cycles. | Using information about the social, environmental, and economic capital of interconnected resource cycles and practices in a proactive manner for decision-making. | Developing a standardized methodology to support predictive decision-making regarding SC resource sustainability, forecasting, and planning. |
| 5 | Expanding R&D and resource management strategies and initiatives to all critical tiers of resources from upstream to downstream. | Full collaborative reporting and incorporation of key SC environmental capital of resource practices in production operations for predictive decision-making. | Full collaborative reporting and incorporation of key SC social capital of resource practices in production operations for predictive decision-making. | Full collaborative reporting and incorporation of key SC economic capital of resource practices in production operations for predictive decision-making. | The interconnected resource cycles of suppliers and other stakeholders are integrated into SCRS reporting and resource management decisions. | Competitive advantage through investments in advanced SCRS practices and strategies for emerging resource frontiers, and future challenges. | Clearly defined SCRS methodology with a robust framework for continuous improvement and circular approach to resource management decision-making. |

Paper Title: Conceptualising A Circular Framework of Supply Chain Resource Sustainability

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SCRS framework case examples: Pedagogical notes

A. SCRS Framework applied to advanced manufacturing supply chains with the constraints of rare earth metals.

For decades, the security of supply of critical and rare earth materials (particularly metals and metalloids), has remained on the radar of big manufacturers like Rolls-Royce and General Electric (GE) as a key commodity risk in financial and insurance projections and assessments. Due to global reliance on these materials across diverse manufacturing supply chains such as aviation, automotive, information and communication, medical and healthcare, and defence, the perceived scarcity of these metals can easily be overelaborated and hence, lead to an artificially induced increase in commodity prices. Furthermore, the sort of extensive materials hedging operations and competitive sourcing typical in these industries often induces a temporal scarcity of these materials across multiple supply chains. This temporal outcome is ineffective because without life-cycle mapping, it leads to an inaccurate understanding of the key resource constraints in the materials supply chain, which could adversely affect the long-term environmental, economic, and social bottom lines of firms that depend on such materials as critical inputs. To address this challenge, companies that are linked to such rare material supply chains can begin by using FP1 to strategise their real materials scarcity, where the detailed steps in Table 1 can aid the operationalization and assessment of the key resource constraints.

After FP1 is understood, it is essential to quantify the environmental, economic, and social capitals of the supply chain resources (FP2). In a recent study, Koh et al. (2016) demonstrated how this can be achieved at the macro-level of resource sustainability using an integrated resource efficiency index to account for the triple bottom line impact of aggregate resource utilization. The steps outlined in Table 1 (FP2a, b and c) can be used to assess the resource sustainability of such rare materials against the three bottom lines at tactical and operational level in the supply chains that depend upon such materials. The actual empirical analysis required to achieve this would involve Life Cycle Assessments (LCA) and supply chain resource modelling (See Koh REF2014 impact case study and Ibn-Mohammed et al, 2016 as examples). Firms like Rolls-Royce now adopt this approach to manage their materials resource sustainability and use LCA augmented with advanced supply chain resource modelling to understand the wider impact of resource usage and adopt an integrated view of supply chain resource sustainability across the three key bottom lines from the outset.

The next step in ensuring long-term supply chain resource sustainability is the evaluation of all the interconnected overlaps of these resources (FP3) from a multiscale perspective. Here, the objective for firms that depend on rare metals is to explore other supply chains where the same (or similar) materials are used to understand the constraints associated with volume, material grade, and sourcing. Operationalising the detailed steps outlined in Table 1 as it relates to the specific case will help firms to optimise the resources acquisition, use and management for the specific product/service supply chain. For instance, both Rolls-Royce and GE use titanium alloy in the manufacturing of gas turbine engines, however, titanium alloy has wider applications in other seemingly unrelated industries, which must be closely assessed for potential synergies (such as in healthcare technology development by Siemens for bones and hips replacement).

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2 A vivid understanding of the key areas of resource interconnectedness will advance the
3 competitiveness of supply chains through the establishment of new synergies and perhaps, the
4 development of alternative resources. Consequently, as outlined in FP4, the focus of competition
5 advances beyond competing supply chains to the level of resource sustainable supply chains, whether
6 they are contemporaries or from entirely different industries with a shared resource constraint. Rolls-
7 Royce's well-known Total Care package for the service, maintenance and overhaul of their gas turbine
8 engines provides a highly competitive offering to airframers and airlines in the civil aviation supply
9 chains. The synergies developed has impacted the innovative initiatives of Rolls-Royce, particularly in
10 their targeted investments into the exploration of lighter materials and alternative fuels to compete on
11 resources sustainability.
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15 As shown in Table 1, FP5 combines the outputs from FP1 through FP4 and presents the most viable
16 propositions or decisions for supply chain resources sustainability. The detailed steps for this operation
17 as shown in Table 1 emphasizes the role of integration in enabling supply chains to make resource
18 sustainability decisions by drawing on a wide range of insights (from FP1 through FP4). For instance,
19 in Rolls-Royce FP5 can act as a key decision making platform for various business units nationally and
20 internationally for optimum efficiency and resources sustainability across the supply chains.
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23 The entire process from FP1 to FP5 is continuous and circular following the theory of constraints
24 principle. The circular framework of supply chain resource sustainability (Figure 1) positions these five
25 foundational premises where supply chains resources sustainability can be referred to at the strategic
26 level, whilst the detailed operational steps are designed to guide through their evaluation during
27 implementation (Table 1). It is vital to highlight that the critical resources (constraints) can change over
28 time, and such dynamic and complex interactions further explain the need for a circular framework that
29 is alive and constantly evolving.
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32 **B. SCRS Framework applied to retail supply chains with the constraints of energy costs** 33 **duplication due to the circularity of key operations (manufacturing, warehousing and** 34 **logistics)** 35

36 The fluctuating prices of food and fast moving consumer goods (FMCG) is one of the most obvious
37 outcomes of perceived resource scarcity, which appears to be invariably related to the instability in the
38 global energy market, driven in part by ongoing economic and socio-political uncertainties. Energy
39 price speculation impacts various sub-stages of food production and FMCG manufacturing (especially
40 upstream at the raw material stages) and thereby, amplifies the bull-whip effect in retail supply chains.
41 Since retail supply chain mapping and resource accounting is not very detailed in most companies,
42 many retailers resort to shifting the accumulated costs from different production sub-stages to the
43 shelves (final consumers), with the attendant risk of increased obsolescence and wastage (Obayi et al,
44 2017). For the most part, the actual contribution of energy to retail prices per commodity is difficult to
45 determine due to the inherent circularity in resource utilization (i.e. manufacturing and logistics costs
46 both include a factor for energy, which tends to be duplicated across supply chains) (FP1).
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50 Drawing on the SCRS framework proposed in this paper, firms in collaboration with their key partners
51 can carry out a life-cycle mapping of the energy requirements at the intersections of various
52 overlapping supply chains to identify hotspots and potential areas of optimization and energy savings
53 that would not only impact shelf prices but also overall resource sustainability in terms of
54 environmental, economic, and social bottom lines respectively (FP2).
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2 Retailers like ASDA have incorporated this principle into their corporate and supply chain strategy to
3 drive down product shelf prices as well as improve overall resource sustainability. By spearheading and
4 fully funding initiatives like the aptly termed “Sustain and Save” platform, the company draws insights
5 from over 1,250 suppliers and partners like WRAP, LEAF, and IGD to map out potential investment
6 opportunities for improving the energy sustainability of their supply network. Since its inception in
7 2013, the *Sustain and Save* initiative has unlocked over £11million in savings and minimised CO2
8 emissions by about 35,000 tones. Beyond the obvious accrual of economic capital, the initiative has
9 yielded substantial social and environmental impacts as well. For instance, in a related scheme called
10 the “waste walk”, ASDA in collaboration with a key supplier *ALPRO* invested in the modification of
11 the cooling systems for soya beans processing, which helped to cut down water utilization by nearly 13
12 million liters and returned the book value of the initial investment in approximately one week!
13 Likewise, by working with *ABP*, a meat producer, a modified ovenable packaging for beef joints was
14 developed, which increased the product’s shelf life substantially and cut down the cost of wastage by
15 about £3.5million (FP2).
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19 If one traces the energy trail from the point of production of fresh foods and FMCGs to the shelves, one
20 is likely to find that the cost attributed to energy consumption is perhaps duplicated in the sourcing,
21 manufacturing, packaging and logistics operations of retailers due to the dense interconnectivity among
22 their suppliers and indeed, among the retailers themselves. In terms of logistics operations, one
23 principal contributor to energy costs is the less than full truckload (LTL) deliveries of independent
24 FMCG manufacturers in the daily replenishment of fresh and perishable products (FP3). A classic
25 example of how the interconnectedness across supply chains can be managed to improve resource
26 sustainability is the recent horizontal collaboration between FMCG rivals, Nestle and PepsiCo, for the
27 distribution of fresh and frozen products in Belgium and Luxembourg. Using the services of a cold
28 logistics specialist, STEF and two neutral trustees to provide legal firewalls for anti-trust compliance
29 and neutrality (Beliliux Association of Branded Product Manufacturers (BABM) and TRI-VIZOR)
30 both manufacturers have bundled their warehousing, packaging and distribution. This initiative has so
31 far unlocked nearly 10-15% cost savings, substantial CO2 emissions reduction, and energy
32 conservation through consolidated full truck deliveries (FTL) to retail clients. In a similar manner, the
33 proposed SCRS framework with the steps/stages itemized in Table 1 can aid the management of the
34 interconnectedness of other supply chain operations with substantial energy constraints such as
35 manufacturing and recycling.
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40 Retail competition is primarily driven by key operational indicators like price, flexibility, availability
41 and quality, as opposed to the brand-based competition that is prevalent in other industries. In addition,
42 consumers have become increasingly conscious of the social and environmental profile of the products
43 they purchase and this has been shown to greatly impact purchasing behavior. Consequently, retail
44 supply chains that are able to systematically address key resource sustainability constraints would
45 undoubtedly outperform rivals on key sustainability measures but in addition, translate the resulting
46 sustainability bottom lines to actual market competitiveness in the long-term (FP4). Top management
47 decisions regarding supply chain optimization and restructuring can thus be progressively improved as
48 managers begin to gain a better mastery of the resource interconnectedness and the triple bottom line
49 capitals (economic, environmental and social) of retail product assortment (FP5).
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52 **C. SCRS Framework implementation in breweries for the management of water availability** 53 **constraints** 54 55

56 The brewing industry is very water resource intensive and it imposes a significant environmental
57 constraint downstream, where portable water is used as a direct input into the final product, as well as
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1 upstream, where the growing of key ingredients like hops and barley requires heavy irrigation. There
2 has been an increase in recognition of resource scarcity across the life-cycle of brewery production
3 processes, with SAB Miller, one of the largest international brewing firms, stating in their 2013 CSR
4 report that their sustainable agenda will see a drive to protect water resources and develop partnerships
5 in their supply chain to ensure agricultural materials are produced in an environmentally and socially
6 conscious way (FP1). This supplier engagement builds upon previous commitments in their 2007 CSR
7 report where priority was placed on working with suppliers to bring in 'best practices' tailored to
8 smaller suppliers that concern soil fertility levels, pest management, biodiversity protection, water
9 management, improving social capital and ensuring suppliers develop local economic impact and
10 development (FP2). Other large brewing companies have shown similar commitments to understanding
11 and managing the interconnectedness and overlaps in resource cycles and across their supply chains.
12 Diageo, which owns world recognised brands such as Guinness and Smirnoff, state in their 2012 CSR
13 report that they are promoting the supply chains of local sorghum crops that are less water-intensive
14 and have lower carbon emissions and is combined with a localised economic development strategy to
15 provide training and technical assistance to farmers in some of the poorest countries in the world. This
16 shows a company using their influence in a global supply chain to improve the resource provision
17 through product substitution and engage with local farmers to promote social and economic
18 development (FP3). The justification of these measures is to ensure that these large companies have
19 access to scarce resources crucial to the production processes of their businesses, and to gain political
20 and social acceptability of their processes and maintain access to these resources by engaging at a local
21 level and maintain their competitive advantage (FP4). These examples highlight the increasing
22 embeddedness of supply chain resource sustainability operations in company decision making, and
23 given the size and global reach of the supply chains of international brewery companies future
24 developments could see explicit predictive decision making and conflict resolution in supply chain
25 management by these firms (FP5).
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