Emerald Journal of Advances in Management Research

Local Water Stress Impacts on Global Supply Chains: Network Configuration and Natural Capital Perspectives

Journal:	*Journal of Advances in Management Research*
Manuscript ID	JAMR-10-2015-0068.R4
Manuscript Type:	Research Paper
Keywords:	global supply chains, local resource availability, supply chain configuration, natural capital theory

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Abstract

Purpose – This paper proposes a novel resource availability assessment for supply chain configuration. This approach involves understanding of both local resource availability and the demand-side implications of supplying global/regional markets as part of a more holistic supply chain design activity incorporating local environmental factors.

Design/methodology/approach - The proposed framework was derived from literature analysis, bridging relevant literature domains – Natural Capital theory, Industrial Ecology, and Supply Chain configuration - in order to develop design rules for future resource constrained industrial systems. In order to test the proposed framework exploratory case study, based on secondary data, was conducted.

Findings – Research findings suggest that this approach might better identify relationships and vulnerabilities between natural resource availability and the viability of regional/global supply chains. Our research suggests that natural resource availability depends upon three elements – local resource consumption, global resource demand, and external environmental factors.

Research limitations – The framework has two main limitations. The current work is focused only on a single industry case study used to exemplify the approach. Secondly, the framework does not consider other possible industries, which might enter or leave the specific location during the company's operation. Furthermore, no assessment was made of migration of populations within the area.

Practical implications – For practitioners, such as those in the agri-food sector, the resource availability assessment framework informs supply chain configuration design. For policymakers, the research aims to provide policy guidelines, which can help to improve water saving strategies for a particular region. At a broader societal level, the research raises awareness of resource scarcity amongst industrial players and the wider public.

Originality/value – A resource availability assessment framework has been proposed, suggesting that the dynamics of both global and local resource demand, in

conjunction with changing local environmental factors, can over time significantly deteriorate a firm's natural resource impact on the local environment. Thus, the framework seeks to deliver mechanisms to evaluate potential vulnerabilities and solutions available to firms through a more proactive supply chain design method and apply reconfiguration processes that account for natural resources, based primarily on network and resource attributes.

Keywords: global supply chains, local resource availability, supply chain configuration, natural capital theory

Paper type Research paper

1. Introduction

As a result of globalisation, national and specific local manufacturing operations have become increasingly embedded within the global economy. This has resulted in a greater interdependence of countries, in terms of product supply, but also the localisation of stress points on the natural resources required in the manufacturing and production process for a wide range of commodities, services, and goods (UN 2008).

Global Supply Chain (SC) networks, are increasingly experiencing resource constraints from commodities such as water in a growing number of locations. This has been brought about by the intensification of local resource consumption in order to supply regional and global markets, and local environmental factors that have eroded natural resource levels and/or increased water stress through greater consumption patterns e.g. through population growth. As a result, water quantity and water quality impacted by both global and local factors can carry potential risks for business operations in particular locations.

Over the last decade, several large multinational companies have become increasingly vulnerable to water related risks in their production operations. These risks include water overuse, droughts, flooding, and water poisoning and have all led to changes within the firm's SC.

Examples of *ground water over pumping* have been found in connection with companies such as Coca-Cola (India) (The Economic Times 2007), Pepsi Co

(Morrison and Gleick 2004), Nestle – Perrier (Brazil) (The Council of Canadians 2014; Brady 2014), and British American Tobacco (Mexico, Cambodia, Brazil) (CDP 2012). In some cases the issue has caused plant shut-downs; in others it has facilitated the employment of water reduction technologies across the SC through the establishment of dialogue with both users and suppliers.

Severe drought influenced the availability of barley and aluminium for Anheuser-Busch (US) (Wells 2014), which led to the utilisation of reclaimed water for cleaning purposes, as well as a replacement of plants that were more drought-tolerant. Prolonged droughts in Brazil forced Solvay (pharmaceuticals, Brazil) (Baida 2014) to close twenty-two output units in Sao Paulo state. Alta Mogiana (sugar processing company, Brazil) (Leslie 2014) supplemented their income with other products, such as electricity generated from burning spent cane stalk. Fbria (textile company, Brazil) (Baida 2014) developed a contingency lab for water education purposes. Recent droughts in California, US (2014) forced MillerCoors (Beverage sector) (Sacks 2014) to switch from metal conveyor belts to plastic ones in order to allow bottles to slide along the belt without any liquid assistance, hence, saving on the amount of water required in production.

Excessive flooding affected British American Tobacco's operations in Malaysia in 2009 (Abdullah 2009). As a result, the company had to import tobacco leaves from other locations to supplement production. In 2011 floods hit a large number of companies with operations located in Thailand. Toyota, Honda, Mazda, Nissan, Mitsubishi, Sony, Nikon, Sanyo Semiconductor, Canon, Western Digital, Hitachi, Hutchinson, and Microsemi were severely affected by this natural disaster and had to halt all production operations (AON Benfield 2012).

Water quality can have an immense effect on the company's production processes. This is a major concern for the food production industry, where food security is of central importance. Poisoned water used in rice fields in Guangzhou, China in 2009 influenced their entire SC. After rice growing was banned in the area, most rice producing and processing companies had to shut down or partially halt production (Jiaoming et al. 2013; Guangwei 2014).

This paper seeks to advance understanding of the causal relationships between two non-static factors; namely local resource availability (or more specifically the shortage of water resources) and the demand side impacts of supplying geographically dispersed markets that form the complex global and/or regional SCs of today.

In order to analyse these relationships, a theoretical framework development through the lens of natural capital theory (NCT) is proposed. The central units of analysis of the work are SC configuration characteristics, including SC network structure, governance structure, process and information flow, and product structure that all build on theoretical developments in SC design and water availability levels. The quantification of water availability is undertaken through its concomitant characteristics captured in water tables, level of urbanisation, climate change projections, and water quality data. As a result, a supply chain vulnerability assessment framework for local water stress and global supply chain evaluation will be developed in the following sections.

The first section reviews the literature on SC characteristics and water availability and quality parameters. The second part focuses on the theoretical development of a SC configuration framework from a natural capital perspective. In the third section the framework is tested through a case study. Finally, a number of areas for future research are set out.

2. Literature review

2.1.Resource availability

Consideration of the natural environment and natural resources used in the production and delivery of goods was first developed through Natural Capital Theory (NCT) originally coined in the 1960-1970s (Hanks 2012; Porritt 2007). The theory, based on premises of economic and ecological economic theory (Hinterberger et al. 1997), emphasises the depletable nature of resources and the effects pollution and ecosystem change have on the environment (Faucheux et al. 1997). These effects, brought about as a result of economic activity, are framed in terms of intertemporal economic costs (Faucheux et al. 1997). Such environmentally disruptive economic activities create irreversible ruptures between short-run performance and long-run prospects for economic output, the resource renewability cycle, and environmental life-support

(Faucheux et al. 1997). An incorporation of NCT into everyday decision-making process of economic, political, social systems (Guerry at al. 2015) is posited to have an immense influence on the future state of the world's ecosystems and human well-being (Helm 2015).

Current research adapts the NCT perspective on natural resource availability to be used for subsequent SC reconfiguration analysis, and as such contributes NCT from organisational perspective.

The issue of natural resource scarcity, and in particular water scarcity, is a growing concern for many economies globally. Many local communities and industries are already severely affected by a lack of water in their locations and highly dispersed supply chains are becoming increasingly vulnerable to local water availability risks. In order to better understand the notion of local water availability, it will be necessary to analyse the following factors: water quality, urbanisation, industrialisation, and change in climate.

2.2. Water supply

The amount of water available for utilisation varies on the geographical features of a region, facilitating the level of natural water supply and replenishment (Hess et al. 2015). Water scarcity emerges when there is "an imbalance of supply and demand under prevailing institutional arrangements and/or prices; an excess of demand over available supply; a high rate of utilisation compared with available supply, especially if the remaining supply potential is difficult or costly to tap" (FAO 2012, FAO 2013).

Falkenmark et al. (1989) present a water stress index based on estimated water requirements for the household and agricultural sectors, the population of an area, and annual water availability (Falkenmark et al. 1989; Mueller et al., 2015). The index provides a simple means of estimating water stress by grading regions across four distinct levels: water secure regions, water stressed regions, regions with water shortages, and water scarce regions (see Table 1) (Falkenmark et al. 1992; Falkenmark et al. 1989; Sarni 2011; Bell et al. 2013; FAO 2012; WRI 2013; Rijsberman 2006).

Please Insert Table 1 “Levels of water scarcity (Adapted from FAO 2012)”

Demand for water varies between different countries depending on both sectorial industrial water usage and consumer use, reflected by levels of (disposable) income (Rajsberman 2006). Additionally, external factors such as climatic conditions, water quality, seasonality, and levels of urbanisation and industrialisation also have an impact on water availability. The index devised by Falkenmark et al., however, does not take any of these factors into consideration in the classification of a region’s level of water stress (Rajsberman 2006; Mueller et al. 2015). Each of these parameters will be considered in turn.

Water quality

Water scarcity is closely coupled with water quality (Sarni 2011). Generally, water scarcity is only determined by the quantity of water available; however, not all-available water is equally suitable for agricultural, industrial, or private sector purposes. A region may have a water supply of over 1700 m^3/per person/per year but if 90% of this water is unfit for use it would be inappropriate to classify the region as water secure. Water quality, therefore, is a relevant factor to be taken into consideration when examining water scarcity problems.

Water quality is defined by its suitability for use (Ayes and Westcote 1976). However, water “always contains measurable quantities of dissolved substances” (Ayers and Westcote 1976, 4) that can deteriorate productivity levels. The level of such substances can substantially affect the level of salinity, permeability, or toxicity of the water (Ayers and Westcot 1976; Ayers and Westcot 1985). Such contaminating substances include cadmium, chloride, chromium, cyanide, nitrite, sodium, and plasticizers (USGS 2014). In certain regions, the implementation of harmful pesticides, fertilisers in agriculture, or inadequate wastewater treatment will frequently result in water contamination. Additionally, water quality can be deteriorated through the “increasing re-use and recirculation of water” (FAO 2012).

Please Insert Table 2 “Water quality”

Zeng et al. (2013) propose a water quality index to measure “pollution induced water scarcity” (p. 444). The index aggregates data across three sectors (industrial, agricultural, and domestic), measures the amount of pollutants discharged into water systems by analysing nitrogen and chemical oxygen demand, and measures the amount of fresh water required to assimilate the concentration of pollutants to a safe level. The proposed formula $I_{grey} = G/Q$ (Q = fresh-water resources, G = grey water footprint or volume of freshwater required to assimilate pollutants to a safe level) implies that the water quality index should be above 1 in order to maintain an acceptable water quality level (Zeng et al. 2013).

2.3.Water demand

Water demand can be characterised as the water footprint of a nation or a particular region (Boyd 2015) showing the total volume of freshwater required to produce goods or services that are consumed by the population of the region (Chapagain et al. 2006). Industrialisation plays a significant role in the availability of water in a particular location due to the intensive concentration of the number of industries in the location as well as the level of water demand required for their production operations.

Various industries have different levels of water demand in their production operations (Table 3). For example, global footprint of agricultural sector accounts 8,363 km^3/year, while industrial sector on average consumes 400 km^3/year (Boyd 2015). Even though the operation process demands of a single operational unit (e.g. a bottling plant) consumes resources within set limits, an industrial cluster within a region (with each unit operating within required limits) can lead to stresses on resource availability. Moreover, if an industrial cluster aims to serve not only the local population but also exports goods and services to other regions then additional stress is placed on local water availability.

Please Insert Table 3 “Generalised water footprint by industry sector (Adapted from Sarni 2011)”

Urbanisation combined with the industrialisation of a region can have an immense effect on resource availability. According to Postel (2000) global urban water demand is growing year on year, contributing to increasing levels of water pollution (Figure 3). Toxic discharges from cities and upstream industries contaminating water with heavy metals and toxins mean that the water is no longer of a suitable quality (Feldman 2012; Brown and Halwei1998; Boyd 2015).

Please Insert Table 4 “Water requirements (Adapted from Davis 2014)”

2.3. External factors

Water supply can be influenced by a number of external climatic factors, including climate change, extreme weather events, and El Niño and La Niña.

Climate change is “expected to account for about 20 per cent of the global increase in water scarcity” (FAO 2007, 15). Changes in climate result in increased droughts, heat waves, glacial melting, early springs, early vegetation, increased evapo-transpiration, changing vegetation cover (due to temperature change**)**, with modified rainfalls in *mid-latitudes* (Jeunesse et al. 2016), high snow falls, increased availability of water at *northern latitudes,* and rising water levels due to an increase in global sea levels and prolonged rain seasons (UCS 2011) in the moist tropics at *higher latitudes* (Feldman 2012).

Evidence suggests that extreme weather events have a direct influence on the increased frequency of droughts, floods, heat waves, heavy rainfall, storms, and tropical cyclones (IPCC, 2012). These extreme weather events have a low probability of occurrence (in a particular place and time) but high impact on resource availability (such as water). At the World Economic Forum (2012) extreme weather events were ranked as the second most significant supply chain disruptor (Bhatia et al. 2013).

Events such as El Niño and La Niña have potentially catastrophic impacts on water availability. The nature of these events is a result of extreme changes in air pressure (National Geographic 2015a; National Geographic 2015b; NOAA 2014). Heavy rainfall, coastal flooding, erosion, droughts, hurricanes, monsoons, and typhoons are caused by these events. El Niño and La Niña have an irregular frequency of occurrence and normally only occur every two to seven years. Neither event, however, can be strongly predicted (National Geographic 2015a; National Geographic 2015b), and given the enormous impact of such events, El Niño and La Niña can carry huge potential risks to SCs and in terms of the focus of this paper, water availability.

Several studies have shown that a combination of changing climate with extreme weather events could result in an exacerbation of demand on water resources (Castex et al. 2015). As a result, these external climatic factors increase risks to global production (Cline 2008), especially in countries of the developing world (Feldman 2012; FAO 2013; Millner and Dietz, 2015) where water efficient practices are not commonly used and climatic conditions are already unfavourable. The current research will therefore consider a number of additional factors, including sector effects, industrialisation levels, changing urbanisation patterns, and geo-climatic conditions (FAO 2012)

2.4. SC configuration and reconfiguration

Globalisation has significantly influenced SC research with much emphasis placed on SC footprints and geographical spread (Olhager et al., 2015). Companies have a number of reasons for locating their supply chains in particular regions (Porter 1994). Conventionally, the driving factors were labour costs, transportation costs, raw materials costs (Daskin et al. 2005; Weber 1909, Hoover, 1918); and proximity to both demand (market) (Von Thunen 1826; Grotewold 1959; ReVelle and Eiselt 2005) and supply, e.g. scarcity rents that result in locating near rare earth resources such as minerals for mines (North 1955). However, this ignores the production processes within the SC as well as geographical features of different locations. Water availability has a direct impact on multinational manufacturers, where the recent trend is towards regionalisation under a focused-factory strategy (Christopher 2005). Concurrently, retailers, expanding their operations beyond their home bases into international markets, are also experiencing increased pressure due to local resource scarcity. As a result, global dispersion of corporate value chains (producers, processors, and retailers) (Mueller et al. 2015), along with uncertainty relating to local resource availability, can impact on the whole supply chain, placing new requirements on SC configuration.

Combining concepts from both strategic and operations management, Srai and Gregory (2008) identified four main dimensions of SC configuration attributes to be considered in supply network design. Firstly, supply network structure considers the number of network tiers involved in the production process and links between them, including: supplier tier(s), manufacturing tier, distributor tier, retailer tier(s), and customer tier(s) (Chandra and Grabis 2007; Lambert 2008; Wisner 2011; Bhadada 2013; Carter et al. 2015). In a competitive environment, managing the supply network base is crucial as 50 percent or more of product value is often created by upstream suppliers (Handfield et al. 1999). The company's production operations and processes can also be dispersed throughout a geographical area resulting in a number of different sites (Srai and Gregory 2008; Lorentz et al. 2013; Caniato et al. 2013; Bolstorff and Rosenbaum 2003; Truong and Azadivar 2005). The optimum configuration in terms of network structure considers the geographical footprint of operations including natural resource constraints.

Secondly, operating in a resource constrained environment global SC process flow design analyses resource intensity in its production/assembly operational processes (Surie and Reuter 2014). In some scenarios where resources are scarce process flow design should ration or minimise such resource use (Bell et al. 2012). Another parameter involved in production flow design is resource quality. Industry sectors vary depending on the level of quality of the resource required for production. For example, the semi-conductor, food, beverage, and pharmaceutical industries all require ultra clean high quality water (Soman 2008; van der Vorst 2000; Sarni 2011; Manivaskam 2011). Traceability of the quantity and quality of the resources used in the production process ensures the future safety of the product (Cooper and Lambert 1997; Roth et al. 2008; Christoopher and Towill 2002***)***, as well as security of the natural environment.

When considering product value structure in global supply chains Pashaei and Olhager (2015) emphasised the importance of integrating product design with process flow development and supply chain design, where architectural attributes of the product are also incorporated with process (Chiu and Okudan, 2011). These serve as coordinated mechanisms in supply chain design (Fisher 1997). A number of parameters in the formulation of the product in terms of raw material resources and components must be considered in SC design shaped by resource scarcity. For example, SC product traceability influences the ability to analyse the amounts of the resource in the product as well as the quality of the resource (Roth et al. 2008). Product waste management provides an opportunity to maximise yields and mitigates potential risks of water shortage and environmental degradation (Beamon 1999, Golinska et al., 2007). Thus, creation of products that use processes which could minimise negative impacts on natural resource availability can drive the design of sustainable supply chains (Jayal et al. 2010).

The final SC configuration dimension involves the governance structure and coordination mechanisms of the SC, which refers to the ways in which SC partner relationships are structured and organised (Kattipanya-ngam 2010). Inter-firm relationships can be considered as a flow of resources (Penrose 1959), and inter-firm collaboration has shown to be beneficial in terms of reducing cost, time and uncertainty (Frohlich and Westbrook 2001; Handfield and Nichols Jr. 2002; Holweg et al., 2005; Simatupang and Sridharan 2005). One of these uncertainties involves resource scarcity, and therefore consideration of the suppliers', customers' and stakeholders' relationships should be a priority when designing the SC (Sodhi and Yatskovskaya 2014).

3. Methodology

The methodological development aims to advance the understanding of how global consumption impacts on local resource availability. Here we develop a bridge between Industrial Ecology literature and SC configuration theory in combination with the Natural Capital perspective in order to generate a set of dimensions for potential resource availability assessment. The conceptualisation of potential influencing factors on resource availability in SC operations design is used to enable identification of SC vulnerabilities and reconfiguration opportunities that can mitigate against identified risks.

SC, within its production operations consumes various natural resources, such as water, air, minerals, etc. For this paper, water resource was selected to demonstrate linkages between natural capital and SC configuration. An extensive literature review on resource availability, supply chain design, and resource consumption patterns facilitated the development of water demand and supply constructs. This was followed by the development of detailed taxonomies of demand and supply factors enabling linkages to be made to sustainable SC configuration design. These constructs with their supporting taxonomies form the development of the conceptual framework allowing evaluation of local resource availability for SC configuration (Figure 1 and Appendix 1). Each of the constructs with subsequent taxonomies is discussed in turn.

The first construct "natural water supply" incorporates a combination of measurable parameters of water resource at the study location. For example, natural water supply parameters, influencing water availability levels for subsequent consumption by industry sectors and population at a given location were identified as constant or variable. Parameters, which are relatively constant and facilitating the resource availability (designated as "+" in Figure 1), include geographical characteristics of the given location, which are characterised by: a) long-term climatic conditions (i.e. precipitation patterns) defined by ten climatic zones (FAO 2006); b) natural water replenishment levels (renewability of water yearly) defined by Falkenmark (Falkenmark et al. 1989; FAO 2006; Table 1); and c) water quality (natural chemical composition of water, including dissolved solids, salts, antimony, barium, beryllium, arsenic, etc. (Figure 1)). External climatic conditions, on the other hand, are variable parameters that can have a positive and a negative effect on water availability at the given location (designated as "+/-" in Figure 1) depending on the nature of the event, including: a) changing weather patterns (higher/lower precipitation, rising sea level, prolonged rain/dry season) (UCS 2011; Feldman 2012); b) extreme weather events with a low probability of occurrence but a high impact, resulting in droughts, floods, heat waves, heavy rainfall/snowfall, storms, cyclones (IPCC 2012; Bhatia at al.2013; Morrison and Gleick 2004); c) El Niño and La Niña, which are climatic conditions caused by atmospheric pressure, resulting in heavy rainfall, flooding, erosion, droughts, hurricanes, typhoons, and monsoons (National Geographic 2015a; National Geographic 2015b; NOAA 2014).

The second construct "industrial water demand" involves the major parameters influencing local water availability (designated as "+/-" in Figure 1) in the area. This is a cumulative result of significant production operations of each industry sector, each company within the sector, and the scale of each plant. The consumption pattern of water (quantity and quality needed) by industry sector varies, depending on the production processes involved (Sarni 2011; Table 3). Local water availability and water quality can be improved if the production processes involve wastewater treatment or water replenishment steps thereby contributing to natural water availability levels (designated as "+" Figure 1 and Appendix 1). Another significant industrial factor influencing local water availability is the purpose of production operations: a) for local supply or b) for global supply. Local supply is determined by satisfaction of the local population needs, whereas global supply presents "virtual water" embedded in commodities and moved away to satisfy global demand without contributing to local communities and potentially causing local water stress.

The third construct is "water available for local population demand" describes local water quantity levels that are left after industrial intake and shared between community members. Local water availability levels are closely linked to urbanisation, number of inhabitants at the given location, and their income levels (Davis 2014; Table 4), which determine resource consumption patterns. Based on the considered parameters (water availability after industrial intake, urbanisation, and level of income (GDP level)) Falkenmark's index is applied. This further results in four possible local water availability conditions (FAO 2012; Table 1): absolute water scarcity, chronic water shortage, regular water stress, and occasional or local water stress.

The last construct "firm SC configuration attributes: responding local water stress" is determined by water availability levels that drive SC re-configuration. Here SC re-configuration is presented by a number of SC attributes with sub-parameters (Srai and Gregory 2008): the network structure (including local supply base and the number of sites in the given location), process flow (including process water intensity, process waste generation quantities, and process water quality requirements), product value structure (including product water intensity, product water quality requirement, and product waste generation), and SC governance / coordination mechanisms (including supplier relationships, customer relationships, institutional relationships, and internal site role in company network structure). All these SC parameters should be reconsidered in order to respond to water availability levels for a given location. Each of these dimensions emerge from equivalent factors used in SC configuration 'network design' studies (Srai and Gregory 2008) but with the emphasis now refocused on designing and redesigning for the sustainability of natural resources, and in this specific case, water resources.

The defined conceptual framing of the problem: that a combination of quantifiable factors (global and local demand), influence local resource availability (local supply), which in turn needs to be managed through an appropriate and sustainable SC configuration and design was developed into the framework allowing evaluation of local resource availability for SC configuration (Figure 1). Additional information and explicit water availability assessment framework for SC configuration is represented in Appendix 1. In order to test the proposed framework we employed an exploratory case study, based on secondary data, to examine the operationalisation of the approach, and explore in further detail arguments for SC reconfiguration driven by local water stress.

3*.1. Case study*

The case selection was determined by its ability to provide a good example of SC reconfiguration strategy as a form of the mitigation of local resource scarcity. Resource shortage at location was primarily caused by a combination of local (changes in climate, population density, water quantity) and global factors (increased SC dispersion and global demand). The study is based on a widely reported historical case of Coca-Cola in Plachimada (India). Data was obtained through secondary sources, including primary data case studies (Hills and Welford 2005; Burnett and Welford 2007, Blacksmith Institute 2014; Sitisarn 2012), reports from the government of India (Jayakumar 2010), Plachimada Supreme court acts (Koonan 2007), and news sources (IRC 2008; RIM 2007; FFFM 2009). These sources of information were chosen to ensure the robustness of the data and to provide potential opportunities to undertake case studies more generally using widely available data sources.

In order to explore the dynamic context, the case study is based on the analysis of three time periods: 1999 before Coca-Cola entered the location, 2003 during Coca-Cola's operations, and 2006 after Coca-Cola left Plachimada. During the seven years of Coca-Cola's operation, there were significant changes in water availability levels that were created by multiple factors including the company's operations. By applying proposed water availability assessment framework to this case study we have examined the state of the location during each three time periods based on three main parameters with sub-parameters: 1) Plachimada natural water supply (climate zone, natural water availability, water quality, external influence of climate change); 2) Plachimada industrial water demand (number of industries operating in Plachimada, number of operation sites with in an industry, site's water demand, global water supply vs. local water supply, waste water generation; and 3) water available for population demand (number of inhabitants and water requirements) (Table 5). Firm SC configuration attributes", containing four sub-parameters, shows the actions the company undertook in order to mitigate water scarcity issue in its operations.

As seen from the Table 5 in 1999 before Coca-Cola moved its production to Plachimada, the area was classified as arable with amount of 3.105 million $m^3$of water a year, water table at the level of 0.65m (Jayakumar 2010), and acceptable quality levels. However, due to insufficient rainfall, Plachimada had already been categorised as drought prone location with 3,140 mm of rainfall annually. The major industry located in Plachimada was agriculture that consumed 2.61 million m^3 of water yearly (Jayakumar 2010). The population of the area in 2001 accounted 54,235 inhabitants whose water demand was equal 0.9268 million m^3/year. From this categorisation, it can be noted that even before Coca-Cola's operations cumulative water demand of the population and agricultural sector had already exceed natural water supply levels by 0.4318 m^3/year.

During Coca-Cola's bottling operations in the area, water tables significantly dropped to the point of 8-13m. Plachimada changed from arable land to a drought-affected area. Moreover, due to climatic conditions the rainfall had significantly reduced to 1337 mm/year. During this time agriculture and Coca-Cola's bottling operations together constituted the major industrial demand for water, which accounted 2.7925 million m^3/year. Seemingly, the amount of waste generated by the company accounted 0.05475 – 0.1095 million m^3/year that also resulted in major water contamination (Global Research 2010). The water shortage problem has significantly affected Coca-Cola's operations due to protests by stakeholders. In 2004, the company was forced by local government to close down the plant.

In 2006, since Coca-Cola left the location, a similar assessment had taken place. The area was still classified as drought affected but water tables had started to recover. The level of water contamination had largely decreased. However, agricultural industry and the number of inhabitants had declined due to insufficient water quality.

The case study shows that during seven years of Coca-Cola's operations local water availability significantly deteriorated (HCC BPL 2002). This was caused by three factors. Firstly, Coca-Cola's bottling operations violated regulations by exceeding abstraction limits (Sitisarn 2010) and releasing sludge, containing high levels of cadmium and lead, to villages (IRC 2006; Jayakumar 2010). Secondly, the location of the plant was initially classified as a severely drought prone area, vulnerable to climate change (Jayakumar 2010). Finally, the district was initially considered as one of the highest, most densely populated areas in the world (Sitisarn 2010). Together these factors resulted in significant water table depletion and significant water quality deterioration (Rohan 2011). The Kerala State government was forced to close down the plant (IRC 2008; Rohan 2011) and the company chose to reconfigure its supply chain by relocating it's bottling operations from Plachimada to Orissa (The Economic Times 2007) (Table 5).

Please Insert Table 5 "Framework verification (Case study Coca-Cola company)"

Please Insert Figure 1 "Water availability assessment framework for SC configuration"

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5. Discussion

Natural capital theory posits that a company's operational processes should be designed with a long-term perspective, enabling the ability to sustain resource renewability cycles and to maintain "environmental life-support functions" (Faucheux 1997, 528). Based on this concept, SC configuration should include assessments of resource availability when establishing the optimal global SC network structure, including natural resource impacts in a particular location. The industrial ecology domain represents a globalised perspective on resource availability assessment within dispersed industrial systems. The integration of these three literature domains has been proposed in order to establish guidance for the design of future industrial systems (Figure 1).

The resource availability assessment framework developed here is based on the propositions that global SCs serving geographically dispersed markets impose stresses on specific local natural resources, and furthermore, that stresses to the local environment, such as climate change, consumption patterns, and levels of urbanisation, also impact on the level of resource scarcity within a given location. Therefore, a multidimensional structure of local resource availability and global (downstream SC) demand should be evaluated in a structured manner to inform SC design and subsequent reconfiguration.

The case study conducted attempts to test the resource availability assessment framework in order to identify industry vulnerabilities and further propose more sustainable SC configurations. The framework involves explicit representation of both local resource availability and global/regional market demand for comprehensive SC configuration design incorporating environmental factors.

As such, the Coca-Cola case study shows that the industrial problems faced by Coca-Cola, would have been predictable using this framework. The dynamic nature of the framework analysing three time series and considers resource availability before the Coca-Cola plant allocation, during plant operation, and after Coca-Cola left Plachimada.

Evidence shows that the average water availability level in Plachimada equals

3.105 (million m^3/year), which aims to satisfy local community demand (0.9268 million m^3/year) combined with agricultural water needs (2.61 million m^3/year) (Jayakumar 2010). This, however, shows that Plachimada's location had been experiencing water stress (location prone to droughts) lacking on average 0.4315 million m^3/year even before the Coca-Cola site allocation (Jayakumar 2010). Further resource availability assessment shows that the company's water intake (0.1825 million m^3/year) had worsened resource availability within the region. Additionally, during Coca-Cola's operation the quality of water was significantly deteriorated by heavy metals (i.e. cadmium and lead) and sludge from the plant reduced the amounts of water available for domestic and agricultural use.

Evidentially, the case study provides explicit evidence that if Coca-Cola had applied approaches akin to the resource assessment approach set out here, the SC structure would have changed towards either less water intensive processes, may have resulted in changing the product structure produced at the Plachimada site, or resulted in other changes to the supply network structure so as to increase collaboration with suppliers in resource abundant areas, appropriately informed by local research centres, and governmental authorities.

From an industrial systems perspective, the framework supports the assumption that local resource consumption, global resource demand and external environmental factors impacting a particular location are essential attributes to determining local resource availability. Furthermore, the assessments made over multiple time periods demonstrate the dynamic nature of the analysis.

6. Implications of the study

The study provides some very important insights on how global SCs that serve geographically dispersed markets can impose stresses on the natural resources of specific locations. However, servicing global and/or regional markets is not the only factor leading to local resource shortages at the point of production, as stresses from local environments, such as localised effects of climate change, the aggregate impact of local consumption patterns, and levels of urbanisation in the locality also impact on the level of resource scarcity within a given location. Any evaluation of SC vulnerability and subsequent reconfiguration of SCs should take into account the dynamic and multidimensional nature of local resource availability and demand (in the form of urbanisation and industrialisation) as well as the impacts of pan-regional supply. The proposed framework aims to understand and predict industrial problems caused by resource scarcity.

The outcomes of the research impact practice, policy, and education. For practitioners, such as agri-food businesses, the resource availability assessment framework aims to make an improvement on general supply chain configuration design. For policymakers, the research aims to provide policy guidelines, which can help to improve water saving strategies for the regions involved. The research contributes to new knowledge in the domain of supply chain management (SCM) and at a broader industry and societal level raises awareness of the increasingly critical issue of resource scarcity.

7. Conclusion and future research

The proposed framework was built upon three literature domains. Natural capital theory, which emphasises the importance of sustaining resource renewability for the long-run perspective of business processes, is incorporated with SC configuration theory, evaluating supply and demand aspects of resource availability criteria in SC design considerations, with design attributes informed by the industrial ecology domain. The framework represents an integrated and global view on resource availability, and its assessment within widely dispersed industrial systems.

Building on these theoretical developments and literature domains a resource availability assessment framework has been proposed, suggesting that global and local resource demand, affecting resource availability, in conjunction with external environmental factors, can significantly deteriorate a firm's operational environment. Thus, the framework seeks to deliver mechanisms to evaluate potential vulnerabilities and solutions available to firms through more proactive SC design and reconfiguration processes that account for natural resources, based primarily on network and resource attributes. The Coca-Cola company case illustrates how the resource availability assessment framework can be used in order to evaluate resource availability related risks within the upstream SC and production process for a regionally and globally dispersed downstream SC and market.

The framework has two main limitations. First, the current work is focused only on a single industry case study. Second, the framework does not consider other possible industries, which might enter or leave the specific location during the company's operation. Furthermore, no assessment was made on migration of the population within the area. Therefore, additional study of a broader set of industry sectors and cases would be beneficial for further refinement of the assessment framework.

Future research to investigate relationships between each of the framework attributes, through quantitative and qualitative research study would be desirable. The future research directions based on the proposed resource availability assessment framework would be the exploration of the relationships between decisions on the operation's location, scale of the plant, and the choice of the technologies for the specific product. Ultimately, the framework might help to develop a more common approach for resource availability assessment via partnering with climate research scientists, internal resource bodies (WRI, FAO), local governments, and industry sectors.

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Table 1. Levels of water scarcity (Adapted from FAO 2012, 7)

Annual Renewability of Freshwater (m^3/person/year)	**Level of Water Stress**
<500	Absolute water scarcity
500-1000	Chronic water shortage
100-1700	Regular water stress
1700	Occasional or local water stress

Table 2.Water quality

Natural water contaminants:	*Literature source*	*Man-made water contamination*	*Acceptable amounts*	*Literature source*
aluminum	Zeng et al. 2012	antimony	< 5mg/L	WHO 2003
barium	Zeng et al. 2012	arsenic	<0.010 mg/L	EPA 2014
dissolved solids	Zeng et al. 2012	beryllium	<0.004 mg/L	EPA 2014
fluoride	Zeng et al. 2012	cadmium	acceptable for domestic/industrial use <5mg/l	ATSDR 2015
calcium	Zeng et al. 2012	chloride	<1mg/L	EPA 2014
iron	Zeng et al. 2012	chromium	<100mg/L	ATSDR 2013
manganese	Zeng et al. 2012	cyanide	<0.07 mg/L	WHO 1996
selenium	Zeng et al. 2012	lead	<0.015 mg/L	EPA 2014
sodium	Zeng et al. 2012	mercury	<0,002 mg/L	EPA 2014
salinity	Zeng et al. 2012	nitrate	<10 mg/L	EPA 2014
		nitrogen	<1 mg/L	EPA 2014
		sulfate	<2000mg/L	Manning 2008
		thallium	<0.002 mg/L	EPA 2014
		zinc	<5mg/L	EPA 2014
		pesticides	<50/cfu/ml	Manning 2008

Table 3. Generalised water footprint by industry sector (Adapted from Sarni 2011)

Industry		*Materials*	*Suppliers*	*Direct*	*Product use*
Food and beverage	Withdrawal Discharge	High Medium	Medium Low (medium for food)	High Medium (high for food)	Medium Medium
Semiconductor	Withdrawal Discharge	High Medium	High High	Low/medium Low	Low Medium
Power	Withdrawal Discharge	High High	Low Low	High High	N/a N/a
Extractive	Withdrawal Discharge	High High	Low Low	High High	Medium Medium
Manufacturing	Withdrawal Discharge	Low to medium Low to medium	Low to medium Low to medium	Low to high Low to high	Low to high Low to high

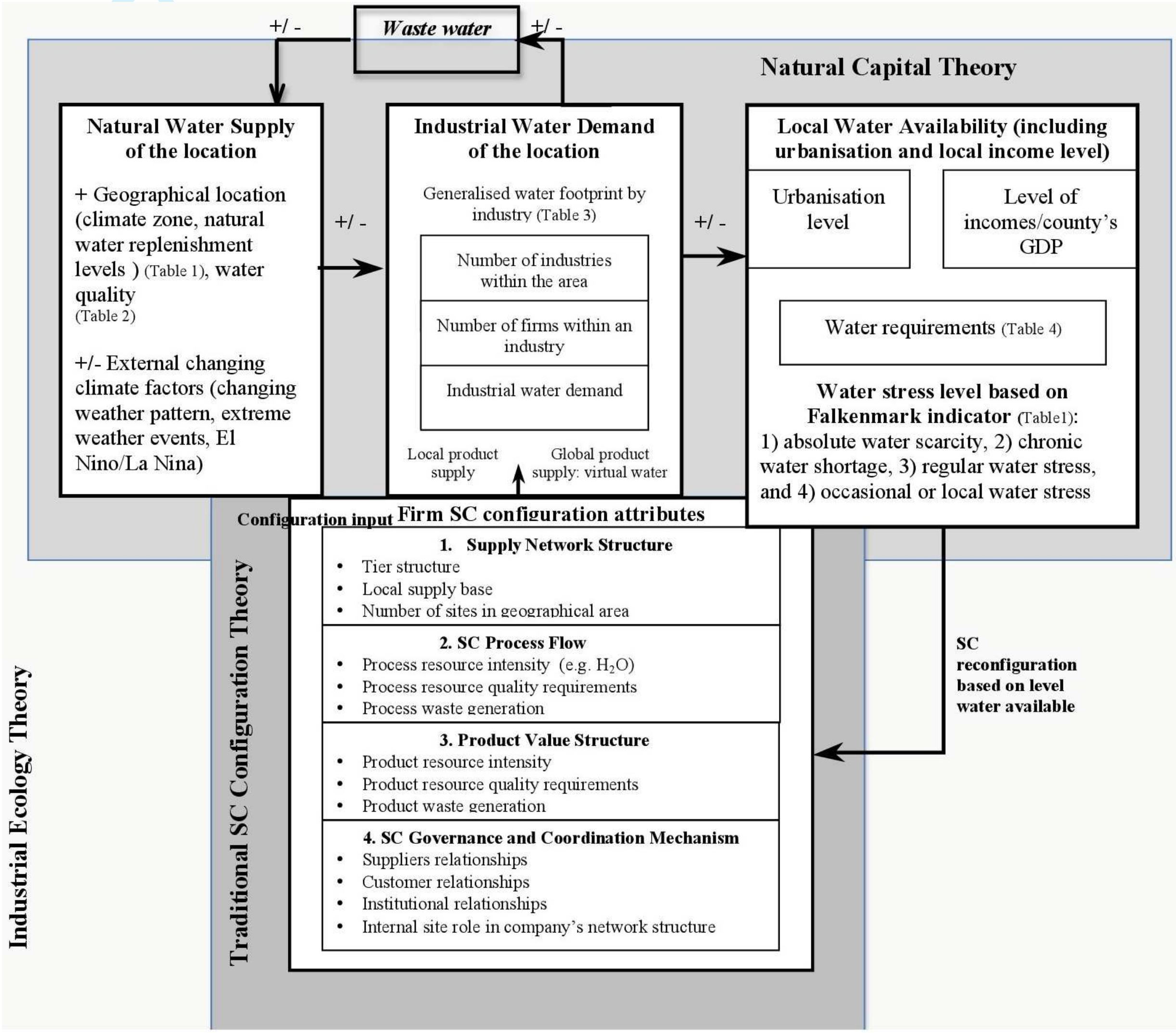
Table 4. Water requirements (Adapted from Davis 2014)

	Water use (litter/capita/day)		
Region	Average	Minimum	Maximum
Developed countries – reported or measured	307	130	578
Newly industrialized countries – reported or measured	199	86	366
Developing countries – reported or measured	44	4	400
African countries – reported or measured	31	5	100
Communities in Central& South America - metered	67	25	133
WHO Standard	50	20	100

Table 5. Framework verification (Case study of Coca-Cola company)

Parameters	**1999 – before Coca-Cola**	**2003 - during Coca-Cola operating**	**After 2006 - Coca-Cola left**
1) Plachimada natural water supply			
a) Climate zone	Wet-dry tropical climate Average water availability: 3.105 million m^3/year	Wet-dry tropical climate Average water availability: **3.105 million** m^3/year	Wet-dry tropical climate Average water availability: 3.105 million m^3/year
b) Natural water availability	Classified as arable land Water table: 0.65 m	Classified as drought affected area Water table 8 - 13m	Classified as drought affected area Water table start to recover 5-7m
c) Water quality	Acceptable	Contamination with: cadmium (0.02 mg/l), lead (0.065 mg/l)	(2007) Contamination with: cadmium (0.007 mg/l), lead (0.142 mg/l)
d) External influence of climate change	Drought prone area Rainfall 3140 mm/year	Rainfall 1337 mm/year	Rainfall 1835 mm/year
2) Plachimada industrial water demand			
a) Number of industries operating in Plachimada	Agricultural Industry Other industries: N/A	Agricultural Industry Beverage Industry Other industries: N/A	Agricultural Industry - reduced Other industries: N/A
b) Number of operation sites with in an industry		Other industries: N/A Coca-Cola: 1 bottling plant	Other industries: N/A
c) Site's water demand	Agriculture: 2.61 million m^3/year	Agriculture: **2.61 million m^3/year – BDL due to poor water quality** Other industries: N/A Coca-Cola: **0.1825 million m^3/year**	Agriculture: 2.61 million m^3/year- BDL due to poor water quality Other industries: N/A
d) Global water supply vs. Local water supply	Agriculture: N/A	Agriculture: N/A Other industries: N/A Coca-Cola: Regional supply	Agriculture: N/A Other industries: N/A
e) Waste water generation	Agriculture: N/A	Agriculture: N/A Other industries: N/A Coca-Cola: 0.05475 – 0.1095 million m^3/year	Agriculture: N/A Other industries: N/A
3) Water available for population demand in Plachimada			
a) Number of inhabitants	(2001) 54 235 people	N/A	N/A
b) Water requirements	0.9268 million m^3/year	**0.9268 million m^3/year - BDL due to poor water quality**	0.9268 million m^3/year- BDL due to poor water quality
4) Firm SC Configuration attributes of Coca-Cola SC			
a) Supply network structure		Regional plant	Moved the plant to Orissa
b) SC process flow		Water intensive bottling operations	
c) Product value structure		Water and waste intensive product	
d) SC governance and coordination mechanism	On invitation on Kerala government Coca-Cola set up the plant	Consumers: Protest against Coca-Cola plant; Kerala State government refuse to renew Coca-Cola a license to operate; Coca-Cola case attracts international attention	Imposed to pay compensation

Figure 1. Water availability assessment framework for SC configuration



Appendix 1. Explicit water availability assessment framework for SC configuration