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## Chapter

# Enabling Sustainable Supply Chains in the Industrial 4.0 Era

*Thuso Mphela, Christopher J. Savage and Alejandro Gutierrez*

## Abstract

Sustainability has become a global policy agenda following the United Nations adoption of Sustainable Development Goals 2030. Supply chains can contribute to this by adoption of eco-friendly technologies, sustainable materials, reducing waste, among others. Adopting and scaling innovative technologies such as machine learning, blockchain, internet of things (IoT), and 3D printing has potential to improve efficiency through improved visibility, flexibility and decision making across the supply chain. Efficiency and lean operations may induce vulnerability in supply chains, due to disruptions like the Covid-19 pandemic which can compromise business. The concept of sustainability is explored from both the business and customer perspectives, as well as in the broader policy environment that includes politics, the economy and society. Businesses are likely to adopt sustainable practices if there are financial incentives. However, environmental sustainability cannot be pursued at the expense of business survival. Therefore, the adoption of different technologies has potential to bring us closer to solving the sustainability-profitability paradox.

**Keywords:** sustainability, logistics, supply chains, internet of things, blockchain, machine learning, 3D printing, efficiency, supply chain risk

## 1. Introduction

Sustainability is not a new phenomenon in business and its associated literature but started receiving greater attention in the supply chain management (SCM) research in the mid-1990s. Unfortunately, a review of literature reveals that most SCM research is slightly detached from the real sustainability problems of the world which include environmental sustainability, reduction in biodiversity, and others [1]. Sustainability is becoming increasingly important not only because of the negative impacts business has had on the environment, but also because customers are starting to use their purchasing power to patronise organisations that are inclined towards sustainability. Although this change in attitude is currently negligible it must have an impact eventually. Recent studies have revealed that despite customers knowing that their choices may contribute to harming the environment, their actions and behaviours seem to not change much [2]. In some instances, customers simply lack understanding on how their choices impact on sustainability. For example, when a customer selects Amazon Prime that promises expedited delivery times, it creates

excess packaging, and poor loading, routing, and scheduling. While the customer may be satisfied, the net effect is an increase in unsustainable outcomes.

Logistics remains a critical component in the delivery of these products and services, and for many companies it is a strategic competitive asset [3]. It is this desire and focus on competitive advantage that may come at the cost of sustainability. The advancement of technology and online instantaneous delivery models have created a customer and society dependent on instant gratification [4]. It is estimated that due to the heightened use of e-commerce the last-mile transportation (B2C) will see delivery vehicles grow by 36% which will result in a 32% increase in emissions in the top 100 cities globally by 2030 [5]. Supply chains have become increasingly more connected, interdependent, and complex, reducing the desired levels of visibility leading to negative ecological and social consequences [6]. Technology may offer solutions to some of these challenges. Current trends of global warming and extreme weather dictate that concerted global effort is vital in adopting sustainable practices. Yet, long payback periods in sustainability initiatives may prove to be a disincentive for businesses [7]. For the latter, financial sustainability, without which they will collapse, remains critical. Therefore, a balance is needed.

The objectives of the chapter are to:

1. Define the concept of sustainability and its application in business operations, with a specific reference to financial sustainability.
2. Discuss components and activities of supply chains and their contributions to environmental sustainability.
3. Demonstrate how technology can be used to integrate sustainability into supply chain decisions in relation to the supply chain components and activities, through the improvement of information and financial flows.
4. Offer a sustainable supply chain governance model that incorporates and balances competing multi-stakeholder interests.

## **2. Methodology**

The Chapter adopts a pragmatist paradigm [8] using a narrative literature review [9], given that the objectives are focused on presenting the current knowledge on sustainable supply chains and showing gaps in their practices, while offering practical tools for improvement. Pragmatism offers flexibility on the choice of methods used in research as guided by the research questions. Therefore, the following approach was taken; (1) Objectives and structure of the chapter (topics to be covered) were discussed and agreed by the authors; (2) Literature was searched from a few databases including Science Direct (predominantly), Ebscohost and Google scholar; (3) Grey literature was added to capture practitioner knowledge and current practices as the subject is constantly evolving; (4) Synthesis of the literature was conducted.

## **3. Sustainability within the supply chain**

As stated in the Introduction, sustainability is not a new concept, and it is a term that is used quite broadly. It therefore tends to take different forms depending on

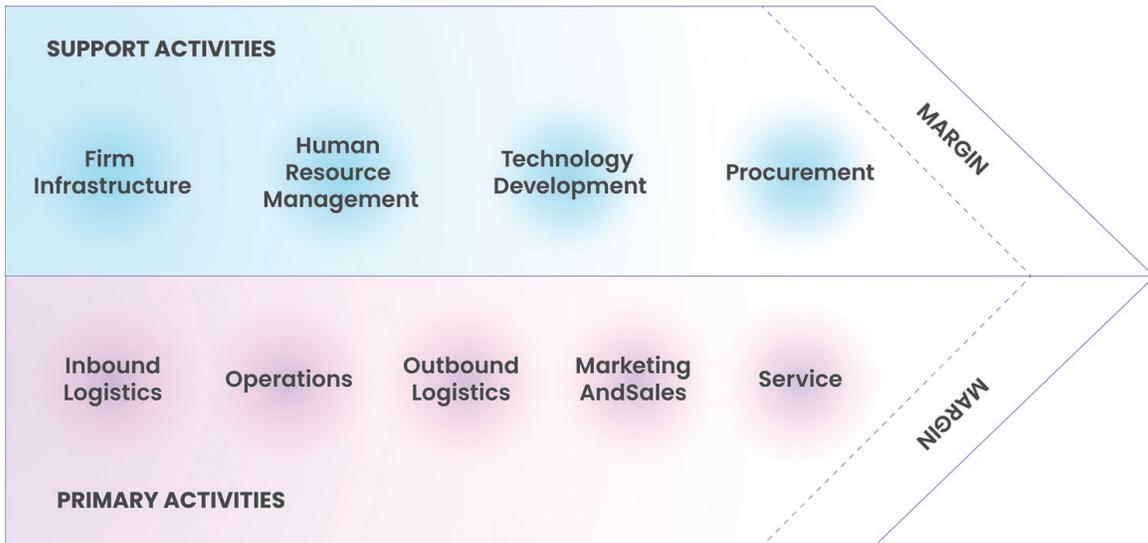
the respective disciplines. For example, a systematic literature review [10] revealed rather divergent areas of sustainability that include Ecological Sustainability, Economic Sustainability and Social Sustainability. Literature commonly presents these as independent concepts. According to the authors, definitions of sustainability in supply chains are disjointed across the literature which makes frameworks for research and practice challenging. In many instances, the concept of sustainability has been narrowed down to very specific areas such as sustainable procurement, production, packaging, and transportation, among others, leading to fragmentation. Generally, sustainability in supply chains has been viewed as attaining a balance between economic, environmental, and social objectives, a concept commonly referred to as the triple bottom line (TBL), and sometimes referred to as Profit, Planet, and People (3Ps). This is reflected and expanded in Searcy's [11] idea of focal firm, supply chain, and sustainability context within which the firm operates. Critically, Searcy emphasises the need for the focal firm and its supply chain partners to consider broader social and environmental boundaries at local, regional, and global levels. This is motivated by the understanding that economic advancement is inherently linked to long-term stability of the environment. To date, the definition of sustainability [12] that posits that sustainability is achieved when current needs are met without compromising the ability of the future generations to meet their needs, remains pivotal both in practice and academia. Incorporating this ideology into SCM to create sustainable supply chain management (SSCM), the authors propose the following definition.

*Sustainable supply chain management is the attainment of efficiency, visibility, and security of supply chain member interactions for profit by harnessing technological capabilities in a way that the current and future economic, ecological, and societal interests are integrated and not compromised.*

This definition brings two new aspects to the definition of SSCM. First, the belief that technology will be a critical driving force given the desired and realistic SCM future. Second, given the need for urgent action to reverse and slow climate change, the ability to meet the needs of the identified stakeholders is already compromised. To put this into perspective, Brundtland made this assertion more than three decades ago.

#### **4. Role of supply chains and logistics in sustainability**

Logistics has become the backbone of business globally. Today, more than ever, the Covid-19 pandemic has demonstrated how the world desperately depends on the movement of goods with container prices growing tenfold from 2019 to 2021. Despite the global disruptions, supply chains have shown resilience in moving what needs to be moved. According to UNCTAD [13], the world ship carrying capacity reached 2.1 billion dead-weight tonnes (dwt) after increasing by 81 million dwt by January 2021. The classical contribution by Converse [14] that recognises logistics as the other half of marketing simply emphasises the position the function occupies in the broader business environment. A supply chain consists of many players (local or international) that work together to create value in an arrangement sometimes referred to as value chains. **Figure 1** below shows a graphical representation of the traditional logistics and value chain activities by Porter [15], made up of primary and



**Figure 1.**  
Logistics and value chain activities. Source: Porter [15].

secondary activities. Primary activities that involve inbound logistics, operations, and outbound logistics among others depend a lot on movement of raw materials, semi-finished, finished goods, services, information, and financial resources between the different players using different modes. Most of the inefficiencies and waste occur when the coordination of these activities fails. For example, wrong forecasts may lead to bullwhip effects creating huge disruptions in supply chains, building up inventory or necessitating expedited shipments. Two cases that are cited [16] of the “Norwegian salmon” and “Rolls Royce wheels” where these high-end products (despite efforts to make their production environmentally friendly), reverse all these gains through increased movement for purposes of “value addition”. In the case of the salmon, it goes to China from Europe for processing only to be shipped back to the west for consumption. This increases the carbon footprint of these products, which unfortunately, is not often captured as a cost in supply chains. Equally, there are still controversies around net benefits on the use of electric cars when the industries that produce them and the cars themselves are still powered by fossil fuels generated energy.

In responding to environmental concerns businesses have adopted concepts such as green logistics and circular economy [17]. The green concept forces businesses to infuse sustainability in every decision made—that holistic optimisation in supply chains should go beyond operational and profit efficiencies but also consider environmental and societal impacts with a view to reduce waste at source. On the other hand, the circular economy concept is driven by the idea that waste can be fed back into the system to harness its value as long as it is possible to do so [18]. In other words, business activities can be arranged in a way that one’s waste serves as an input for another’s production. Materials are re-used until they can no longer be useful, thereby delaying their disposal. To that extent, ecosystem- models like business clustering have made this possible. Some traditional industries have incorporated partial recycling simply as a cost saving measure without being concerned with sustainability - for example, steel production uses scrap iron as a component (often 15–25%) of refined steel finished products. By contrast Just in Time (JIT) has led to clustering of component industries around major manufactures - e.g., in the European automotive industry.

## **5. Augmenting sustainability efforts through technology**

The Fourth Industrial Revolution (4IR) presents great opportunities to revolutionise supply chains, changing how products and services are designed, produced, distributed, and disposed [19]. Broadly, integration of 4IR and sustainability goals has potential to improve chances of attaining positive environmental and ecological outcomes [20]. Despite this, challenges in the adoption and implementation of 4IR initiatives for sustainable supply chains range from organisational, technological, strategic, ethical and legal issues. These are especially true for the developing world. Faced with these challenges, the following technologies are potential gamechangers. By far the greatest benefits are improved visibility, flexibility, security, and integration over a complex web of different supply chains, with sustainability as the likely outcome.

### **5.1 Machine learning**

Inventory and warehousing are some of the main contributors to inefficiencies in the supply chain. Overstocking is a common practice across warehouses around the world. The main reason behind this is the limited information available to decision makers regarding how external factors can impact their operations.

Machine learning provides solutions in the form of inventory control towers that enables recommendations based on data previously gathered. The algorithms created can identify the impact of external and internal factors on inventory cycles upstream and downstream [21]. Also, it allows prediction of potential imbalances in supply chain networks providing reaction time to redistribute goods in a more efficient manner. The result of this is improved energy efficiency and reduced greenhouse gases (GHG) emissions.

### **5.2 Blockchain and internet of things (IoT)**

Supply chain sustainability risk (SCSR) is prevalent because buying firms possess little information about their suppliers and their operations [22]. New technologies like Blockchain and IoT devices are providing a path for companies to solve issues related to visibility (provenance, fraud, and democratisation of data). It is important to mention that lack of visibility can create inefficiencies within supply chains directly impacting on the sustainability of company operations. IoT leads to improved profitability through in-built supply chain flexibility, optimised shipments and reduction of excess production [23].

IoT devices can be defined as the latest generation sensors that have the capabilities to track, collect and transmit multiple parameters like geo-positioning, temperature, pressure, gas concentration among others in real time. Having access to this data in real time allows supply chain practices not only to take better decisions, but also have a better data for future analysis. IoTs have been successfully used to define the provenance of sensitive goods allowing customers to take better decisions on their sustainable journeys.

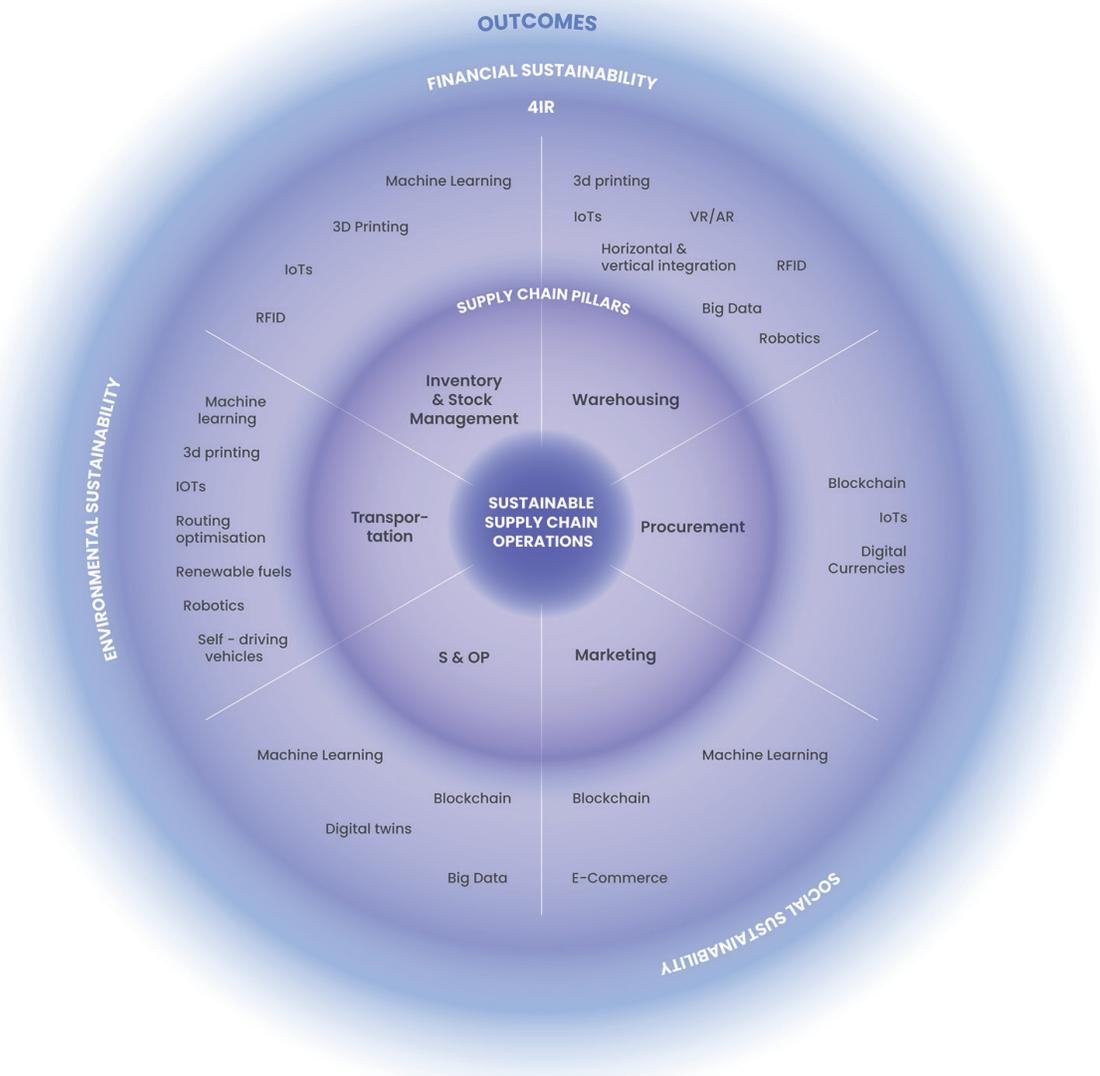
Blockchain is defined as a “public ledger in which each node in the blockchain network stores the same ledger” [24]. The adoption of Distributed Ledger Technologies (DLT), like Blockchain, in supply chain management is advancing rapidly in top tier companies. Blockchain is providing a foundation to reduce silos across the supply chain flows (physical, financial and informational) as it allows for integration of multiple legacy platforms with new solutions like IoTs. One of the most important

characteristics of DLTs, which is also very attractive to the business community, is the immutability of the data recorded [25]. This feature provides companies and customers with a level playing field, resulting from distribution of power [26], where concepts like greenwashing are not relevant anymore due to visibility and the provenance provided. Furthermore, DLTs provide a chance for brands to involve customers in their validation frameworks due to the decentralised nature of these solutions.

### 5.3 3D printing

Companies are integrating critical parts of their supply chains in order to have better controls and increased suitability efficiencies. 3D printing has become a perfect initiative for companies to regain control of their own supply chains. The Covid-19 pandemic has highlighted how companies have become extremely dependent on outsourced manufacturers located in places far from where their markets are.

## Sustainable Supply Chains 4IR



**Figure 2.** Sustainable supply chains 4IR. Source: Authors illustration.

3D printing and point of sale production can have a dramatic impact in the sustainable strategies that companies are putting forward. One of the benefits that can be identified from 3D printing is the decrease in long-distance shipping and fossil fuel consumption. The idea is that as long-distance shipping decreases, the last mile will increase due to production sites being closer to final consumers. Also, 3D printing will have a long-term impact in physical warehousing as the need for spare parts and storage will be minimised. Parts will be replaced by blueprints that can be used when required. These actions will save resources currently needed to run facilities and greatly reduce the waste coming from obsolete stock and unused spare parts.

It is worth mentioning that 3D printing can be more energy intensive than traditional methods, but overall, across the whole supply chain there is a greater positive impact when considering not just the manufacturing processes.

Since Porter's value chain framework was introduced in 1985, supply chains have evolved with environmental and societal concerns becoming more significant. Cashflow as opposed to profitability has also become a critical indicator for a healthy business. The advent of 4IR has catalysed this trend, promising accelerated positive outcomes if done right. **Figure 2** above shows a transformed value chain whose players are more integrated in a complex network than before, enhancing visibility and thus offering the potential for flexibility and agility in response to changing circumstances.

## 6. Why does sustainability matter?

This section discusses the views of the different stakeholders on sustainability. In the beginning, the divergent views are discussed independently and subsequently synthesised to demonstrate their congruence and incongruence at the same time. The bigger question is whether these seemingly competitive views can be reconciled or not.

### 6.1 Policy view

Governments play a critical role in sustainability through policy, law, and investments. Despite the urgency to cut carbon emissions significantly, the United States of America (which is the second highest emitter after China) withdrew from the Paris Agreement under the Trump administration, only to re-join when President Biden took over. Law on methane taxation and tax credits on electric cars is facing resistance from both the Republican party, petroleum companies and third-party lobbyists. China is still non-committal on its plans to cut emissions. On a positive note, the European continent through its Green Deal has aligned its development agenda to attain 55% emission cuts by 2030. Substantial financial resources have been committed towards the eight actions identified including transportation, energy, industry, research, and innovation [27]. By contrast, the developing world does not have the luxury of resources commanded by their developed counterparts. Inevitably, this will keep sustainability off the developing countries' tables as they have more pressing priorities such as dealing with poverty, hunger and failing healthcare. In 2015, the United Nations COP21 agreed that the developed member countries will jointly raise USD100 billion to fund climate mitigation and adaptation plans for the developing world. Six years later, this is proving to be a challenge. On the other hand, politics, especially in working democracies can bring about change if the electorates are

informed and demand sustainable development policy. The decarbonisation of development has catalysed investments in clean energy, sustainable industry, development of electric cars, intensified research, and development in sustainable solutions. In the Netherlands, every new law passed, and policy made has to reflect their effects on sustainable development goals. At global level, the United Nations (UN) sustainable development goals (SDGs) 2030 have set the tone with the desire to achieve a sustainable future for all.

## **6.2 Business view**

The need for businesses to be financially sustainable cannot be over emphasised. Again, businesses remain committed to creating wealth for investors, unless they have very clear social goals. Even then, [28] who claims to have coined the term triple bottom line (TBL), observes that 25 years later business thinking has not changed much. He asserts that business executives would “move heaven and earth” to ensure they reach their profit targets but the same cannot be said about the other two dimensions – people and planet. Part of the reason why businesses were reluctant to fully embrace sustainability was the idea that it only added costs and constrained economic performance [29]. Does sustainability pay? Using game theory, findings [30] demonstrated that businesses would invest in sustainability only if the demand-enhancing effect supersedes the cost-increasing effects especially when managerial incentives are subjected to negative rewards. From a business perspective, they may need government policy incentives to nudge them into sustainable practices [31]. Unless integrated global policies that motivate businesses to adopt sustainable practices are developed, the future looks bleak for both the planet and people.

## **6.3 Customer view**

In the Introduction section of this Chapter, the customer is identified as a critical stakeholder through their choices of products and services. Their purchasing power gives them leverage as agents of change to influence business decisions, especially where sustainability is an important consideration in product choices. Whereas knowledge can be (and remains) critical, in some cases it does not shape action. In the UK, a study by Hornibrook et al. [32] that followed an observation of no discernible effect of carbon labelling on customer product choices, concluded that lack of awareness and understanding of carbon labelling were among the major contributors to low carbon products unfavourable uptake. The evidence points to either an informed customer but little will, or uninformed customers (who are the majority) with no appreciation and requisite tools to make sustainable decisions. Knowledge on sustainable practices is even limited in high institutions of learning in present-day USA [33]. Heeren et al. [34], however, demonstrated that knowledge was insignificant in predicting behaviour when controlling for attitudes, norms, and perceived behavioural control variables of the Theory of Planned Behaviour. Even though this study was also carried out on university students in the USA, the message is that there needs to be more than knowledge to realise the desired change in behaviour towards sustainable practices.

## **6.4 Societal view**

Recent years have seen socio-economic inequalities widen despite the advancement of technology and innovation that promised democratisation of economies.

According to the International Labour Organisation (ILO) [35] it is estimated that modern day slavery reached almost 25 million cases globally as of 2016. On the other hand, poor countries and those with low latitudes are disproportionately affected by climate change [36]. From a societal perspective, despite supply chains offering them choices, if not practised in a responsible manner, they have the potential of impacting lives and the future of the next generations negatively. Families are separated through forced labour while other vulnerable societies are exposed to harsh climate consequences. An existential threat is a reality. In the early 1990s, businesses started the incorporation of more socially responsible practices and the triple bottom line (TBL) reporting was born. According to Slaper and Hall [37], comprehensive investments that considered the people, planet and profit will likely support sustainable goals. The idea is that society through its forms (legal and political) can exert some pressure on business to act both ethically and morally. Society also desires to see governments taking action against polluters and irresponsible supply chains by making them pay for their deeds [11]. Unfortunately, global society hardly has a unified view on a wide variety of issues including sustainability. Societies tend to be heterogenous and have low issue agreement, making them very weak in putting pressure on the market players [38]. It makes sense to argue that societies are part of a political system that continually polarises them. On the world stage we have already seen how polarising politics can be on issues of sustainability in the USA elections. If society is to have any significant influence on sustainability, there is a need to confront an arena where power dominates knowledge [39].

### **6.5 Conglomerate (or summary) view**

Societies, especially those that are vulnerable see sustainability as an urgent matter that should be prioritised by policy. Ironically, when the same society assumes the customer cap, they lose their power of influence driven by either selfish gains (instant gratification) or lack of appropriate tools to exercise this power. The business community is looking for incentives to do what is “right”, but in some instances doing the right thing may lead to bankruptcy and collapse. On the other hand, government becomes the hope through policy—this may prove ineffective when political mileage is the ultimate goal of politicians, overpowering scientific evidence. At the end of it all, no matter what the view or interest is, everyone shall pay for the severe consequences of nature when supply chains practices are oblivious of sustainability concerns.

## **7. Sustainability vs. financial sustainability**

Ever since the concept of ‘supply chain sustainability’ was first mooted, there has been a debate around its possible conflict with profitability. One problem is that, in some cases, there is confusion between environmental (green issues) and commercial sustainability. This phenomenon is particularly noticeable in developing countries’ small transport businesses, where a typical reaction from an operator when asked about sustainability could be, ‘I don’t have time to worry about that green stuff, I have to concentrate on paying my bills and putting food on my family’s plates’ [40].

There is a genuine fear in many businesses, especially small and medium sized ones, that the short-term costs of operating in a sustainable manner will outweigh any longer-term benefits. This fear can become acute in businesses that operate in a hand

to mouth manner, i.e., those that need all their available cash to operate and pay wages and so have insufficient money with which to make provision for the future. In some cases, this fear can be very real, businesses do not fail because of lack of profitability but they will fail, sometimes very quickly, when the cash-flow dries up [41]. In other words, if there is a risk that the immediate investment needed to generate sustainable benefits could lead to business failure and even bankruptcy, there is very little chance that those investments will be made. This is particularly sad because, in many cases, strategies designed to give environmental benefits will also create operational cost reductions. For example; efficient routing and scheduling will reduce fuel bills and allow more 'drops' to be completed in a given time [42], whilst good warehouse management systems can have a major positive impact on supply chain efficiency and effectiveness [43] and therefore on both sustainability and operating costs.

Seeking long-term benefits can also cause problems. For example, extending one's supply chain with a view to taking advantage of the low prices or variety offered by globalisation, increases the risk of failure as has been unfortunately demonstrated by supply problems encountered during the Covid-19 crisis. This has led to many companies reversing their globalisation efforts (e.g., by re-shoring) to shorten their supply chains and reduce risks, sometimes at a short-term reduction of profit or even financial loss to enhance longer term viability. Some businesses, that were unable to react quickly to the changing circumstances, failed.

Nevertheless, the key would seem to be to take a long-term view, but this can be difficult when one is fighting for survival. One way to reduce the short-term cost of implementing sustainability measures is to co-operate not just with one's own partners and suppliers but across, as well as, up and down supply chains, even with competitors. Such practices, which hitherto would have been an anathema to many businesses, have come to the fore in recent years where sharing data and even transport can be shown to be mutually beneficial to facilitate survival and enhance sustainability [44].

Green supply chain management and other sustainable concepts are slowly gaining popularity in developing countries. If sustainable supply chain management practices are to be fully adopted by all organisations, a demonstrable link between such measures and improving economic performance and competitiveness will be needed [45]. In particular it is essential that any short-term operational costs are not allowed to inhibit potentially beneficial moves towards sustainability. Perhaps the key is to be found in collaboration through technology to minimise both costs and risks, whilst avoiding cyber information risks [46].

## **8. Governance and sustainability**

One of the principles that runs through this Chapter is the need to consider sustainability of the varied stakeholders. Only when economic, environmental, and social sustainability concerns are integrated throughout the decision-making process can you achieve sustainable development [47]. One of the reflections is that despite knowledge of the need to balance these three concerns, in practice, this has been harder to achieve. Even though sustainability in principle is an inclusive concept and possesses broader stakeholder interests, some of the interests have not been sufficiently represented. Consistent with the 'leave no one behind' principle embedded in the SDG 2030, the governance framework on sustainability should be formulated to include even the least of interests. Access to accurate, immutable, and timely data on local, regional, and global supply chain networks and activities promises information

symmetry that allows accountability and gives power to policymakers and society in decision making and influences the conduct of the supply chains. The same technological capabilities driving global supply chain excellence can be harnessed to facilitate sustainability in them.

Calls for governance models that decentralise and realign decision-making in a manner that drives inclusion through stakeholder engagement, empowered participation and engaged decision making have been made by researchers [48]. Sustainability governance models have taken different forms including community, state, or private-led initiatives. Debates on which approach(es) is effective ensue. Private governance is normally driven by certification processes based on standard norms that individual companies across the chain commit to adhering to. Companies are incentivised through access to premium markets using certification that is recognised and practised by both producers and buyers. According to Grabs [49], the ability of private governance initiatives to play any meaningful role, depends on whether they can be scaled and institutionalised in a given sector. Grabs' study found that, despite the advancement in the sustainable norms and institutionalisation of standard setting, integration of social and environmental externalities into production and procurement of highly priced certified products remains a challenge. Considering the complexity of global supply chains, sustainability governance presents a huge challenge. Advancement in technological tools affords an opportunity to counter this. Generation of sustainability data that can be visibly and timely circulated among the critical stakeholders can re-shape power balances and accountability in supply chains [26]. Using a sustainability matrix in the US agri-food supply chains private-ordering systems proved that continuous improvement in sustainability, can be achieved.

## 9. Conclusion

It is axiomatic that supply chains are not only essential to the twenty-first century way of life but that they have a major influence on the environment and therefore on their own sustainability and that of our planet. It is also apparent that most people that have the luxury of being able to think about it, would like to minimise and ideally reverse their impact. Unfortunately, 'thinking' and 'doing' are often worlds apart from each other and reality.

Even if one accepts people's good intentions, it is apparent from this chapter that, confusion reigns. So many things influence sustainability through supply chains, that it is difficult to know where to start, but some things are very clear:

- Technology offers many techniques to tackle the problem or (in the modern idiom) 'provide a -solution'. For example:
- Physical distribution aids such as: Drone technology and its adoption into mainstream parcels delivery can assist addressing the 'last mile problem'.
- Technology such as: 4IR can provide data and visibility of supply chains.
- Such tools are simply enablers. Like every claim made by a software salesman, the savings can only be achieved if people act effectively on the information they provide.

This chapter has shown that 4IR technologies offer an unprecedented, if confusing, wealth of data and visibility with which to manage our supply chains so that, if we desire, they can become sustainable both environmentally and commercially. Importantly, that opportunity is only meaningful if the right policies, as well as leadership, exist and that global supply chains should be made more honest and open to scrutiny. Above all, environmental sustainability can only be achieved if, at all levels, from corporate down to personal, we put the planet before people and people before profit – in other words, we all aspire to use 4IR technology to become ‘global citizens’.

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