Towards Sustainability Goals in the Portuguese Ornamental Stone Industry's Supply Chain 4.0

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Summary: *In the age of Industry 4.0 (I4.0), the advent of new digital disruptions has brought about a positive impact on supply chains (SC). This has caught the attention of both researchers and practitioners, who are now exploring the potential of these disruptions, especially in relation to sustainability. However, despite this growing interest, the research on this subject remains in its early stages and lacks cohesion, with limited collaboration between academia and policymakers. Thus, the aim of this paper is to investigate how these technologies can redefine company processes and SC in the Portuguese ornamental stone (POS) industry. The primary goal is to identify novel capabilities within the SCOR model that can contribute to sustainable performance and facilitate the achievement of the 17 Sustainable Development Goals (SDG)..*

Key words: *Ornamental Stone; Industry 4.0; Supply chain 4.0; Sustainability; SDGs*

Introduction

The pace of raw material demand worldwide has surged in recent decades. This growth is driven by the rapid industrialization of emerging economies and excessive material consumption in developed nations. The interconnected global SC are vital in meeting our daily needs in every single society, as almost everything we rely on goes through them. However, due to the vastness of these transactions, there is a cause for concern, prompting the global community to recognize the urgent need for practical solutions. Climate change data indicates that global warming is projected to increase (IPCC, 2018), while social issues have been exacerbated, especially with the arrival of the COVID pandemic and the adverse effects of globalization. Also, Russia's war on Ukraine has severely disrupted global markets, exposing vulnerabilities to the supply of raw materials necessary for industrial production and fuelling inflation.

The growth of construction, manufacturing, and energy industries depends heavily on mineral resources, making them valuable economic assets in the regions where they are discovered. Portugal has a rich and complex geology, resulting in substantial mineral wealth, including numerous deposits of ore, industrial minerals, and ornamental stones (OS). Many small and medium-sized enterprises (SMEs) are actively exploring these resources, focusing on the quality and diversity of base ornamental stones, as well as precious metals like lithium. These mineral resources and OS are currently being exploited, transformed into finished product and delivered local and worldwide through SC. However, the lack of effective land-use policies to safeguard the access of the extractive industry to these places poses a significant risk to current and future production. This jeopardizes the contribution of this sector to the national economy and the supply of future generations, making it imperative that action is taken.

Across the globe, both governments and businesses have taken decisive action in reply to the pressing issue of sustainable development. They have committed to fulfilling the United Nations' 2030 agenda, which outlines 17 critical goals for achieving sustainable development. The agenda underscores the importance of collaboration and coordination among diverse stakeholders and across SCs to achieve a balance between economic, environmental, and social dimensions, as highlighted by Luthra and Mangla (2018).

The OS industry's supply chain (OS-SC) involves multiple stages, from quarrying and extraction to the final distribution of refined stone products. Quarrying is followed by processing, where stones undergo cutting, polishing, and finishing to enhance their quality and appearance. Processed stones are then categorized based on various aesthetic factors and stored in warehouses. From there, stones are sold to distributors, wholesalers, and retailers, who play crucial roles in sourcing, processing, and selling the products. Challenges in the SC include responsible sourcing,

sustainable practices, fair labour, and efficient transportation logistics. In addition, technological advancements, such as digital platforms and online marketplaces, have also influenced the industry. Overall, the SC in the OS industry is a complex network that continues to evolve based on sustainability concerns, technological advancements, and changing consumer preferences. To tackle the sustainability challenge, OS-SC, as the overall SC, should consider transitioning to a digital ecosystem. This shift will help in creating resilience and developing the necessary abilities to steer the OS-SC towards sustainability strategically. (Cañas et al., 2020).

The fourth industrial revolution, also called I4.0, has ushered in game-changing technologies such as IoT, Blockchain, robotics, and artificial intelligence (AI) (Almeida & Silva, 2020). The idea of exploring the effects of I4.0 technologies on sustainability performance has become increasingly relevant since the adoption of the 2030 Agenda, opening a vast field for researchers and practitioners to explore the impact of I4.0 technologies on sustainability performance (Sachs et al., 2019). One crucial aspect of sustainability is traceability, which has been emphasized by the UN Global Compact and Business for Social Responsibility (BSR), with Blockchain technology expected to play a vital role in achieving this goal (UN & BSR, 2014; Khanfar et al., 2021).

There have been efforts to create a sustainable OS-SC using I4.0 technology and to achieve the UN's SDGs. However, these efforts haven't shown significant results yet. The current literature lacks comprehensive frameworks that address the intersection between SC 4.0 capabilities, sustainability's triple bottom line, and the 17 SDGs. To bridge this gap, this research aims to address the complexities involved in redesigning OS-SC, assess the potential of I4.0 technologies in enhancing sustainability performance across the set of SDGs, and highlight sustainability capabilities to uncover the interplay between ecological, social, and economic dimensions within the SCOR model processes. A preliminary framework is presented to visualize the potential connections between SC 4.0 capabilities, sustainability dimensions, and SDGs.

Theoretical Background

-Sustainability and Innovation in the POS Industry

It is an established fact that the traditional linear industrial economy operates by extracting natural resources, converting them into goods, distributing them, and ultimately discarding them as waste (Ashby, 2015). The cost of resources has historically been declining in real terms, providing little incentive to conserve them throughout the 19th and 20th centuries. However, since the turn of the 21st century, this trend has been reversed, and the cost of materials and energy has steadily increased, putting immense pressure on SC due to increasing demand from rapidly growing economies. For an economy to be sustainable, it needs equitable patterns of production and consumption. Amid increasing competition between industries, it's crucial to adopt a practical approach that optimizes production costs, enhances quality, and reduces lead times. Organizations have recently been focusing on creating practical strategies to boost their performance, accuracy, reliability, decision-making abilities, control, and flexibility (Silva & Almeida, 2020). Furthermore, the manufacturing sector has been incorporating closed resource cycles into its I4.0s to support sustainable operations management (Russo et al., 2019).

Our daily lives heavily rely on mineral extraction and processing products, which are crucial for various industries such as construction, pharmaceuticals, and cosmetics (Azapagic, 2004). While it is expected that the stock of POS suitable for building, decorative construction, or artistic purposes will remain economically extractable for the next 500 years (Carvalho et al., 2018), continuous mining and large-scale surface stone extraction have resulted in environmental, economic, and social sustainability issues that pose challenges to the POS sector. As a result, weighing the impacts of their actions on the environment, economy, and society has become a crucial consideration for the POS industry, rather than just focusing on profit and economic efficiency.

The extractive industry plays a crucial role in boosting the economy, but its resource-intensive practices have raised concerns about its long-term sustainability in today's environmentally conscious era (Careddu et al., 2019). The OS industry faces significant sustainability challenges, including extractive waste, waste from stone processing plants, and issues with critical and secondary raw materials (Kulczycka & Dziobek, 2021). Failing to adhere to legal and environmental standards could result in serious ecological and safety issues for businesses. The OS industry's environmental impact is significant and visible, especially in vulnerable areas. This impact can lead to habitat destruction, loss of fertile land, and damage to historic archaeological sites. Waste management is also a significant issue for the stone industry. Therefore, companies are responsible for protecting the environment and ensuring natural resource sustainability. As stone is a natural product with varying characteristics, manufacturing may require discarding some parts, which must be done individually. In countries with developed OS industries like Portugal, waste from natural stone processing plants creates environmental and economic problems if not adequately managed. Additionally, customers' growing

environmental concerns and the adoption of transparency processes in the value chain (Mehta & Chahal, 2021) signal the need for a globally connected network of companies in the OS industry.

In today's building and construction industry, there is a noticeable rise in the use of sustainable OS products (Liu et al., 2022). Customers who desire modern designs incorporated in point-of-sale displays are willing to pay more for eco-friendly options. Stone's natural and long-lasting appearance and minimal environmental and social impact make it an attractive choice. Companies must adapt to changing customer preferences to remain competitive and satisfy their clientele. Therefore, they need to find ways to meet these demands quickly and efficiently. However, it is impossible to eliminate material scraps in the POS production chain completely. Therefore, the most effective solution is to reuse materials that cannot be sold as OS (Moreira et al., 2022). A triple bottom line strategy is essential for preserving existing resources instead of acquiring new ones. This approach requires active maintenance and waste reduction measures. To achieve this, all stakeholders in OS-SC must collaborate and generate ideas to extend natural resources' useful life and facilitate easy reuse. Government-funded initiatives for waste management and social behaviour change programs can also be helpful.

Therefore, a comprehensive approach focusing on stakeholders' well-being, concerns about resource depletion, waste disposal, industry members' survival, and market communities' economic issues is necessary to ensure sustainability in the POS industry.

-Bridging Sustainability & Industry 4.0 to Supply Chain 4.0 in Ornamental Stone sector

The fourth industrial revolution involves integrating modern smart technologies to automate traditional industrial operations. According to the literature, I4.0 technologies can reduce transactional costs, increase business value creation, enhance flow transparency, and decrease carbon emissions (Fernando et al., 2021). I4.0 pertains to the current trend in automation technologies in manufacturing, including the POS industry.

In a factory setting that incorporates I4.0 technology, machines work together in a network to create flexible and intuitive systems that can quickly respond to human input, and feedback gathered through interactions with objects during the manufacturing process (Faller & Feldmüller, 2015). Many POS companies have already switched to I4.0 to achieve production flexibility and offer mass customization to their customers (Won & Park, 2020). However, the digital transformation of manufacturing and production processes is an inevitable reality. This represents a new era in the industrial value chain organization and control. To remain sustainable and competitive, businesses must fully embrace I4.0's mobilizing effects (Caiado et al., 2022). This will lead to the creation of the next generation of factories that leverage Cyber-Physical Systems (CPS) (Lee & Lim, 2021) to support production, resulting in "Smart Factories for the Internet of Things" (also known as "digital factories"). Smart factories aim to improve efficiency, reduce waste, and increase productivity. Innovative methods come with risks, but they can be reduced by using performance simulation tools that suggest potential scenarios during production and real-time physical experimentation (Diao & Sum, 2022). To adopt this innovative industry paradigm, POS companies need to restructure their production process; however, there is no universal standard for adopting I4.0 as every case is unique and dependent on the organization's maturity. An inter-operable global SC should have shared knowledge of I4.0-related concepts and digital technologies aligned with specific conditions, regardless of geographical region (Rosário & Dias, 2022).

The mobilization and technological change in the POS sector align with two Sustainable Development Goals: SDG9 (Industry, Innovation, and Infrastructure) and SDG12 (Responsible Consumption and Production). This approach emphasizes the importance of sustainable industrial policy, I4.0 technologies, digital transition, and new skills development to foster European competitiveness of the sector. According to Silva and Almeida (2020), the integration of these elements is key to achieving this goal. The upcoming industrial mindset focuses on sustainability as a design principle. The priority is to extend products and materials' lifespan while maximizing their value. To achieve this, all companies in the industry sector need to follow a common agenda accepted by stakeholders along the SC (Frazao, 2019). The adoption of a unified framework that enforces decisions based on sustainability's triple bottom-line principles, the SDGs, and the globalization background is, therefore, crucial.

The implementation of I4.0 has revolutionized SC management by creating an integrated ecosystem fuelled by advanced technologies (Javaid et al., 2022). The POS industry is starting to adopt some of the most researched and widely used technologies, such as blockchain, the internet of things, big data, cloud computing, robotics, sensors, 3D printing, and AI. (Silva & Almeida, 2020; Frazao, 2019). Known as drivers of change, these technologies support sustainability at every level (Centobelli et al., 2020). Supply Chain Council, a global non-profit organisation, has developed a process reference model called SCOR (Supply Chain Operations Reference) to provide a comprehensive and standardised set of definitions and best practices for

managing and optimising SC. It provides a common language and structure for understanding and evaluating different aspects of the SC, which helps organisations analyse and improve their SC performance (APICS, 2017).

SCOR framework is designed to simplify the language used to describe SC management by categorizing the following six process categories: plan, source, make, deliver, return, and enable. The latest version of the framework recognizes I4.0 techno-logies and consider them as emerging practices (SCC, 2017). These technologies have the potential to drive process excellence across all six levels of the SCOR Model (Table 1), transforming traditional SC into connected ecosystems enabled by seamless planning and execution systems, visible logistics operations, autonomous transactions, smart procurement and storage, efficient and timely spare part management, and advanced big data analytics (Ivanov et al., 2019). SCOR framework fits in OS-SC management.

Table I. SC4.0 process quality criteria built on SCOR model processes

SCOR Model Processes Process	Process excellence criteria in Supply Chain 4.0
Plan (involves activities related to developing a supply chain strategy, including demand and supply planning, resource allocation, and capacity planning)	Modal optimization Efficient and lean planning Improved sales and operations planning Accurate forecasting
Source (focuses on activities related to sourcing and procurement, including supplier selection, negotiations, and supplier relationship management)	Optimized & efficient sourcing Long standing Supplier relationship Sustainable and responsible sourcing Supplier diversity and development Improved supplier's collaboration
Make (encompasses activities related to manufacturing and production, such as production scheduling, quality management, and maintenance)	Lean manufacturing Efficient waste management and disposal Improved manufacturing quality Efficient resource management
Delivery (involves activities related to order fulfilment and delivery, including order management, logistics, transportation, and customer service)	Transport optimization Efficient packing, pick & put-away Optimized loading Sustainable transportation modes Automated administrative tasks Traceable transactions/products
Return (deals with activities related to reverse logistics, product returns, and managing customer complaints or product recalls)	Electronic returns tracking Traceable transactions/ products Efficient returns management
Enable (comprises processes associated with SC management such as business rules, facilities performance, data resources, contracts, compliance, and risk management)	Continuous improvement and measurement

Blockchain is one of the most innovative technologies. The block architecture of Blockchain is able of storing and transmitting data with the added benefits of traceability, privacy, security, and transparency (Habib et al., 2022). Smart contracts (self-executing and ensuring trust between parties) are a key feature of the Blockchain. They reduce repetitive tasks, save transactional and administrative costs, and add value to contracts (Christidis & Devetsikiotis, 2016). Blockchain technology is particularly useful in SC management, measuring carbon footprint, product traceability, and product authenticity, as per Zkik et al. (2022) and Ayan & Güner (2022) explain. It also benefits the environment and society, such as supporting job creation, facilitating humanitarian SC, and improving environmental goals like water sustainability (Zhao et al., 2019). In addition to IoT, Blockchain, RFID tags, or connected sensors are emerging techno-logies with interoperability capabilities (Zhao et al., 2019). Keeping devices and actuators linked to the internet is crucial in today's world (Ayan & Güner, 2022). Mainly in smart industries, warehouses, and transportation, physical systems continuously transmit a large amount of data to the network. Real-time data generated by IoT helps organizations manage waste, recycle, reuse, recover, and remanufacture, resulting in economic and environmental benefits (Cañas et al., 2020; Silva & Almeida, 2020).

I4.0 are also significantly impacted by AI and advanced analytics. In addition to allowing companies to anticipate demand, predictive analytics also helps them avoid delays, surplus production, and inefficient loading (Matenga et al., 2022). Moreover, robotics and intelligent autonomous vehicles consistently perform repetitive tasks (Phuyal et al., 2020). Arunmozhi et al. (2022) report that they are extensively used in warehouses and distribution centres, leading to increased efficiency and sustainability benefits, including emissions reductions, cost savings, and social welfare improvements.

- *Pathways to Sustainability and 17 SDGs in POS industry's 4.0 Ecosystem Supply Chain*

The concept of SC 4.0 involves an interconnected ecosystem where all stakeholders work together to achieve resilience, innovation, and sustainability in pursuit of SDG 9 (Javaid et al., 2022). This approach uses I4.0 technologies to optimise design, management, and planning. However, there are challenges and research issues to be addressed. Real-time market intelligence is needed to predict future demand and understand customer behaviour. Data analytics can help minimise stock inventory while maximising customer service levels. AI and machine learning can be utilised to allocate production capacity and schedule maintenance to minimise disruptions.

Additionally, I4.0 technologies can be used to select suitable suppliers and coordinate operations among partners. This is done using Blockchain technology to share data across SCs and coordinate operations among partners in the I4.0 environment. This system is complex and data-rich, with data analytics playing a crucial role in evaluating and optimising performance. As a result, companies can gain valuable insights through data-driven SC analytics and make optimal decisions to gain a competitive edge.

To achieve the SDGs in the POS industry, implementing a 4.0 ecosystem in SC must be considered. This is a process that needs to describe the activities associated with integrating and enabling SC strategies. These include the creation of and management of business rules; performance management through continuous improvement; managing data, information, and SC

technology; human resources management; contracts and agreements management; network design, regulatory and compliance management; risk management, Environment, Social, and Governance (ESG) management; enterprise business planning, segmentation creation and management; and circular SC management.

Using the SCOR model will provide an integrated, simultaneous, and connected framework for evaluating and improving performance across OS-SC levels. Moreover, integrating the drivers of sustainable SC 4.0, the SCOR model can be used, step by step (following the Table 1 six SCOR framework processes) to find categories of novel capa-bilities that will facilitate sustainable performance and 17 SDGs achievement (Figure 1).

A SCOR process begins with Planning. A streamlined and responsive planning process is enabled by Industry 4.0 technologies, which facilitate trust, transparency, and stakeholder collaboration. As a result of real-time collaboration, companies can maintain close relationships with their suppliers and monitor their compliance with environmental and social standards (Mondejar et al., 2021). As a result, SDGs 10 and 3 are achieved. As a result of this collaboration, progress towards the SDGs will be enhanced, eventually leading to the achievement of SDG 17.

SCs can gather verified information about suppliers by incorporating these technologies into their Sourcing processes, including their working conditions, contractual terms, and environmental impact. With blockchain technology, for example, suppliers can verify and authenticate labels and certifications (White, 2017). SC partners are more likely to collaborate with local businesses and trust new suppliers when they can access information about their suppliers' economic, environmental, and social conditions (Kshestri, 2022). SDG 8 is therefore achieved as a result. Furthermore, using AI to optimise routes and loads reduces costs and increases environmental benefits.

The use of smart Manufacturing in the POS industry creates a triple win by boosting production, improving worker safety, and reducing resource consumption, waste, and emissions (Birkel & Müller, 2021; Hofmann & Rüsch, 2017). In addition, blockchain technology simplifies reporting procedures and provides reliable data on emissions, social conditions, and governance (ESG) statistics to stakeholders (Kopyto et al., 2020). As a result of this process, SDGs 12, 13, 14, 15, 3, and 5 can be achieved significantly.

Deliveries are the last mile, and they require an ecosystem that promotes sustainable practices, rethinks asset utilization, and utilizes data. Figliozzi and Jennings (2020) states that electric and autonomous machines and vehicles for manufacturing processes or transport are crucial to driving sustainability. Further, AI can reduce costs and improve the environment by optimizing routes and loads at the last mile.

SCs are challenged by Driver scarcity. To address this issue, technology enables gamified training programs that attract young workers. Simulators provide novice drivers with a safe environment for practising operating large machinery. Investing in effective training systems (Chaim et al., 2018) contributes to higher quality education, decent work, and economic development (SDGs 8 and 4).

Collaborating with customers is critical to achieving sustainable Returns. In the era of Industry 4.0, processes can be streamlined, and transaction tracking can be

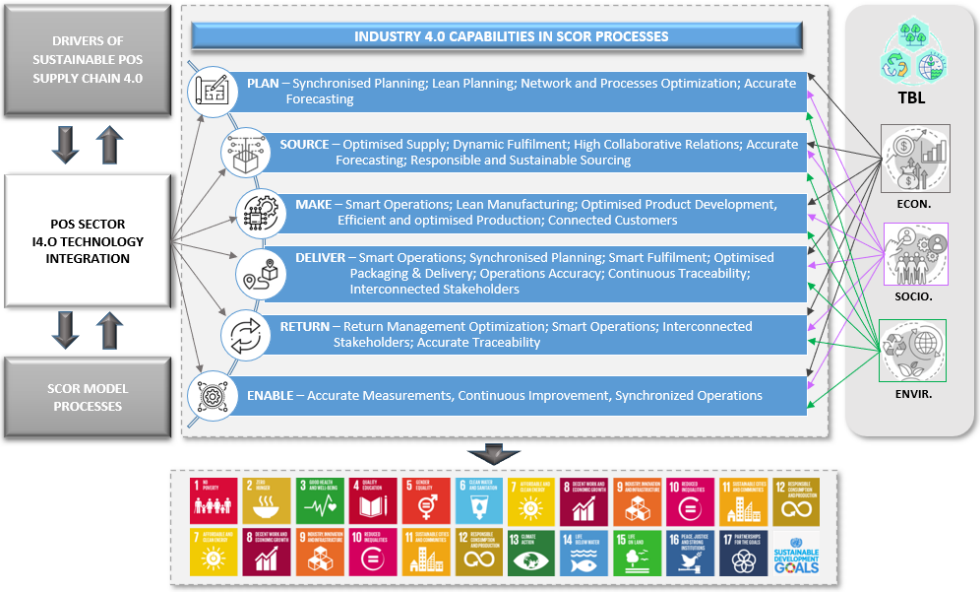

Figure 1. Driving SCOR processes towards the 17 SDGs in POS industry's 4.0

more efficient (Yadav et al., 2020). Using Big Data and AI will provide customers with insight regarding optimal timing and drop-off points, reducing energy consumption, emissions, and costs (SDGs 12 and 13).

Lastly, the Enabling process enhances evaluation, allows constant improvement, and synchronizes operations. As a result of Process 6, the company strives to identify, reduce, and eliminate suboptimal processes to meet its goals and initiatives (SDGs 17 and 9), as Ferreira et al. (2021) explained.

Final Remarks

This research delves into how OS-SC processes can be transformed by I4.0 technologies. It emphasizes the importance of understanding these technologies and their characteristics to effectively integrate them and pursue the Sustainable Development Goals (SDGs). The study draws on literature to connect Industry 4.0 technologies' capabilities to SCOR processes and evaluate their impact on the SDGs. While these technologies bring significant advantages to sustainability, the UN's agenda has interconnected goals that necessitate collaboration among stakeholders and synchronization of supply chains to drive systemic change. Advancements in technology can result in industrial growth, which can raise greenhouse gas emissions and exacerbate social inequalities. Thus, investments in technology should be accompanied by redesigning business models, employee training, and increasing stakeholder participation. To achieve the SDGs, it is fundamental to transform the OS sector and its SC and use sustainable technologies. This paper offers research perspectives on SC 4.0's potential in meeting all SDGs. It suggests redesigning OS-SC by integrating appropriate technologies, monitoring, and involving all stakeholders. Future research should focus on empirical work to investigate how SC 4.0 capabilities can impact the SDG agenda. Additionally, research can be expanded to examine SDGs not directly linked to technological advancements, such as SDGs 1, 2, 6, and 16. Data-driven approaches are necessary to analyse and evaluate the impact of Industry 4.0 technologies on the SDG agenda.

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