Whitepaper

INNOVATION & SUSTAINABILITY

THE EFFECT OF INDUSTRY 4.0 TECHNOLOGY ON ECONOMIC, ECOLOGICAL & SOCIAL SUSTAINABILITY IN LOGISTICS

arvato

MANAGERIAL SUMMARY

Logistic service providers (LSP) are pressured to deliver order fulfillment services while at the same time working towards more sustainable business conduct while minimizing negative impact. LSPs are hopeful that the use of innovative technologies will enable them to meet the demands of the dynamic industry, but they remain uncertain about the actual impact. Rising awareness and pressure around sustainability in (global) supply chains from governments, customers, and consumers force logistic providers to rethink their value chains and move away from a purely economic business model to a more balanced strategy for pursuing sustainability, including social and environmental issues.

The Fourth Industrial Revolution (Industry 4.0) emphasizes digitalization, automation-, and analytics technologies, such as Cyber-Physical Systems, the Internet of Things (IoT), Big Data, Artificial intelligence (AI), and Augmented Reality. In downstream areas of supply chains such as warehouse and order fulfillment, technologies like automated storage and retrieval, robot-piece picking, or AI vision can overcome challenges such as higher customer expectations, next-day delivery, order tracking, increased (network) collaboration, agile pricing, and service quality.

Interviews with innovation and sustainability practitioners were conducted to further examine the role of Industry 4.0 technologies (I4.T0) on the sustainability of LSP and gain insights into implemented projects. Results show that I4.0T technologies can have a net positive impact on economic and social sustainability but an unpredictable impact on environmental sustainability. By gaining an overview of the total impact of Industry 4.0 technology (I4T), we can understand the technology's true opportunity and costs. Innovation often reduces the total cost of ownership and brings stability to costs, making it key to achieving economic sustainability. However, environmental sustainability is dependent on the scope and type of technology used, and businesses must consider the negative externalities, such as more material usage, associated with innovation. Meanwhile, embracing innovative technological solutions can positively impact social sustainability, improve brand image, and address demographic shifts. Yet, return on investment (ROI) remains the critical decision-making factor, and businesses need to shift their value proposition to include stakeholders along the value chain rather than just shareholders. This means we fundamentally need to rethink our definitions of costs, revenue, and profit, in short, our meaning of value.

However, practitioners acknowledge that companies must also overcome six challenges if they want to unlock the full potential of these advanced technologies and gain a competitive advantage in the market: technological adaptation from manufacturing to logistics, trust issues, no errors allowed, treating I4.0T projects like other projects, lack of information, and missing half the benefits.

"It's time to break free from the limitations of the past. Let's adopt a visionary approach to decisionmaking that looks beyond our walls and positions us for success in a constantly evolving business landscape."

Karoline Kowalik,
Author and Logistics Engineer at Arvato

CONTENT

1 INTRODUCTION: IT IS THE YEAR 2024

It is the year 2024, where Western Europe and North America find themselves in the aftermath of a transformative period shaped by a global pandemic and a host of other significant events. As we navigate the repercussions of these unprecedented changes, it becomes evident that our societies and economies have undergone substantial shifts.

In the wake of the pandemic, traditional brick-and-mortar businesses faced challenges, leading to an accelerated digitalization trend. Online sales and food delivery services experienced remarkable growth, revolutionizing consumer habits and supply chain dynamics.

Technological advancements also played a pivotal role in shaping the current landscape. Artificial intelligence became increasingly integrated into daily life, with AI chatbots and image creators streamlining various processes. Meanwhile, self-driving cars have emerged as a viable option, redefining the future of transportation.

Western Europe, however, grappled with economic difficulties, experiencing a technical recession that posed significant challenges. The region faced the complexities of managing hyperinflation, necessitating adaptive measures to ensure financial stability.

The global population crossed the 8 billion mark, ushering in a new era with heightened demands for resources and a pressing need for environmental consciousness. The escalating frequency of extreme weather events further underscored the importance of sustainable practices and climate action.

In the realm of communication and connectivity, the advent of 5G technology has had a profound impact. This high-speed network has opened up possibilities for innovation [I4.0T], from enhanced virtual experiences to the seamless integration of the Internet of Things. Moreover, the geopolitical landscape saw notable shifts, exemplified by events like Brexit, which continue to influence regional dynamics and international relations.

As we confront the challenges and embrace the opportunities that 2023 presents, a spirit of adaptability and forward-thinking will be instrumental in shaping a prosperous future. Through strategic planning and collaborative efforts, we can navigate these transformed times and build resilient societies that thrive in the face of change.

~ Chat GPT after a prompt with selected events and trends of the 2020s by the author.

1.1 THE TURBULENT LOGISTICS MARKET

In the dynamic landscape of 2023, characterized by rapid digitalization, economic challenges, and transformative technologies, the significance of these trends cannot be overstated for the supply chain industry. Adapting to the post-pandemic era, leveraging AI advancements, embracing sustainable practices, and capitalizing on connectivity will be vital for supply chain professionals to optimize efficiency, mitigate risks, and ensure seamless operations in an increasingly interconnected world.

Supply-chain companies have to balance rising pressure to be competitive, become more sustainable, and manage customer expectations while handling increasing order volume and peak moments such as Christmas. Currently, there are 6 areas of disruption in logistics in Western Europe and North America.

Innovation technologies might be a way to deal strategically with these challenges, helping LSPs strengthen their USP and become resilient to disruptions. But that means that decision-makers need to gain insight and understand hidden interdependencies and mechanisms of relevant technologies on sustainability performance.

Figure 1: The six challenges in logistics

ONLINE SALES GROWTH

In 2018, global e-commerce sales were about 3 billion dollars and this number rose by 73% to 5,2 billion in 2021 and is forecasted to grow to just over 8,148 billion dollars by 2026 (Chevalier, 2022). The growth in e-commerce is specifically felt in logistic-focused countries such as the Netherlands: In 2018, 9.2% of the Dutch domestic product (€55 billion) was produced by the logistics industry through operations such as storage, transportation, and distribution (Onstein, Visser, Tavasszy, & van Ham, 2016).

RESOURCE SHORTAGE

In addition to growth, order-picking centers also face the issue of real estate and labor shortage: For example in the Netherlands, the average ratio of worker-to-open vacancies is 1:4 (for every applicant, there are four open vacancies) (Intelligence Group, 2019). Reasons for staff shortages include demographics (aging population), increased demand in skill sets, unattractive salaries, and cost-cutting measures leading to a lack of training (DHL, n.d.). Furthermore, real estate is scarce and hinders logistic service providers (LSP) from expanding their warehouse and infrastructure network to meet demand. For example, in the Netherlands, only 800.000 m2 will be available on the market in 2023 and even more restrictive policies for the construction of large-scale distribution centers will be implemented (CBRE, 2023), making efficient space usage a key topic for LSP.

CONSUMER EXPECTATION

Furthermore, warehousing/order fulfillment centers are especially facing most of the mentioned challenges due to high visibility to end-consumers: 81% of companies compete on customer experience (Pemberton, 2018), such as fast and reliable, (next-day) delivery even during peak. 47% of consumers would abandon a brand they love after a bad shipping experience (Convey, 2021). Many of these services are often fulfilled by 3rd party providers. Therefore, a bad service does not only negatively impact the logistics provider but also its customers and all suppliers along the supply chain. Information transparency increases through the Internet, which enables customers to compare companies and easily switch after a bad experience.

THREAT OF NEW ENTRANTS AND REDEFINING COLLABORATION

Not only does technology enable customers to search for information, but it also allows new ways of communication and collaboration: new entrants focus on agile/adaptive pricing and sharing economy and resources through crowdfunding. Despite the recent decline in e-commerce and signs of recession, a report by (Gosling, Hausmann, Pena-Alcaraz, & Woelfel, 2023) show that logistics start-ups have received more than 12.9$ billion in funding in 2022. While the growth in funding may decelerate, the number of new companies in the transport and logistics sector is expected to rise: "The industry's current customers and suppliers may end up being the biggest new entrants" (Tipping & Kauschke, 2016), but also companies from other industries, such as food delivery and technology integrators, are tapping into the logistics market, adapting some of their traditional services to logistics. Lastly, redefining collaboration through standardization and network collaboration can be an opportunity to stay competitive but also be a threat at the same time if companies do not adapt quickly to the ongoing transformations. Accordingly, competitive advantage is achieved through adapting to new technologies, collaboration, and new attractive pricing models rather than through traditional warehousing and delivery services.

SUSTAINABLE SUPPLY CHAINS

In 2023, the **EU Corporate Sustainability Reporting Directive (CSRD)** was introduced and came into effect the following year as it is still being finalized. CSRD requires companies to report on environmental, social, and governance topics such as resources used, social matters such as treatment of employees, human rights, anti-corruption, and diversity, (European Commission, 2023). The aim is to disclose information to investors and stakeholders on risks and opportunities and to evaluate sustainability performance. In addition to policies, a mindset shift drives younger consumers. 73% of Generation Z consumers, born between the mid-90s and early 21st century, think a sustainable purchase is more important than the brand itself (Hardcastle, 2022) leading to 30%of Gen Z buying second-hand/resold clothing (Pandurangi, 2023). So, companies are influenced by Generation Z to adopt sustainable practices or otherwise risk being exposed to negative publicity and the loss of sales (Wood, 2022).

TECHNOLOGICAL ADVANCEMENT AND READINESS

At present, technological innovation is considered the main disruption to the logistics industry. With the emergence of AI and big data, companies increasingly need to digitize their operations to remain competitive. Examples of new technologies, collectively called Industry 4.0 technologies (I4T), include blockchain, augmented reality, robotics process automation, autonomous logistics, and big data analytics. Not only do companies have to implement these technologies but they must become digitally fit, which means they have to embrace a digital culture and match data analytics and digitization with their corporate strategy and daily operations. The report by (Tipping & Kauschke, 2016) points out that 50% of organizational leaders consider technological readiness and understanding as the biggest challenge.

1.2 TURNING THREATS INTO OPPORTUNITIES

Instead of seeing all six threats as independent areas of disruption, they can be combined and influence each other. **Industry 4.0 technologies** support an organization by

- **providing intelligence to production processes,**
- **providing transparency for managerial decision-making,**
- **increasing space utilization,**
- **improving customer experience, and**
- **increasing (network) collaboration, agile pricing, and service quality.**

While many managers thoroughly understand the impact of investment decisions on their processes and economic sustainability, they neglect hidden costs and benefits up and downstream of their value chain, especially regarding the ecological and social dimensions:

"How will different Industry 4.0 technologies impact the economic, environmental, and social sustainability of logistic service providers?"

By researching the positive and negative impacts of individual technologies, the paper provides an overview of situations and factors influencing the perceived and realized benefits and attempts to answer when managers have to accept trade-offs.

2 INDUSTRY 4.0 TECHNOLOGIES AND SUSTAINABILITY IN LOGISTICS

2.1 WHAT IS INDUSTRY 4.0 TECHNOLOGY?

The term “Industry 4.0” (I4.0) was first used by the German government during the 2011 Hannover Fair (Zhou, Liu, & Zhou, 2015). The Fourth Industrial Revolution is defined as a period that emphasizes **digitization, network communication, automation technologies, and analytics.**

Commonly, it includes technologies like the Internet of Things (IoT), Artificial Reality (AR), and robotics and combines them with data analytics to derive information for decision-making and respond to real-life changes (Lasi, Fettke, Kemper, Feld, & Hoffmann, 2014).

INDUSTRY 4.0, IN COMPARISON TO INDUSTRY 3.0, CAN

deal with a variety of individually unique products and situations,

take decisions autonomously,

collaborate with humans, and

provide interconnectivity and transparency of a whole value chain instead of single processes.

Figure 2: Characteristics of I4.0 based on Torn & Vaneker (2019)

Industry 4.0 technology (I4.0T) is characterized by its connection to information technology (IT) (Lasi, Fettke, Kemper, Feld, & Hoffmann, 2014) and other internet-linked technologies like the Internet of Things (IoT), forming cyber-physical systems (CPS) (Hermann, Pentek, & Otto, 2016). This connectivity, aided by big data and information systems, enhances transparency, decision-making, and autonomous learning within systems. Core technologies identified include Cyber-Physical Systems (CPS), networks, IoT, Autonomous Robotics, Big Data, Cloud Manufacturing, and Augmented Reality (Schmidt, et al., 2015). Recent advancements also encompass simulation, system integration, additive manufacturing, cloud computing, and software-as-a-service (SaaS) (Tjahjono, Esplugues, Ares, & Pelaez, 2017).

2.1.1 INDUSTRY 4.0 TECHNOLOGIES IN LOGISTICS

Efthymiou & Ponis (2021) identify eight key technologies in logistics[1]. Examples of I4.0 technologies at Arvato are depicted in blue:

3D PRINTING

ADVANCED ROBOTICS
Robot depalltizer & AGVs

AUGMENTED/ VIRTUAL REALITY
AR glasses for maintenance

BLOCKCHAIN

CLOUD COMPUTING & BIG DATA
Digital control tower and fraud detection

CYBER-PHYSICAL SYSTEMS
RFID tags in fashion

INTERNET OF THINGS
Autostore/Shuttle (Sensors, conveyor, AI cameras)

SIMULATION AND DIGITAL TWINS
Process simulation

Figure 3: Key industry 4.0 technologies in Logistics
[1] See appendix for a definition of all technologies

2.2 WHAT IS SUSTAINABILITY IN LOGISTICS ANYWAY?

In 1987, sustainable development was widely accepted as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). In other words, future generations should not have to compromise on their quality of life because of past legacy. The Sustainable Development Goals (SDGs), which were adopted by the United Nations in 2015, is a universal call to action to governments, but also companies, and other actors to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity.

A sustainable company should measure success on its economic performance (profit), social impact on stakeholders (people: customers, employees, community, and society), and environmental impact (planet: nature, resources, emissions). By including all stakeholders, rather than just shareholders, in decision-making, companies shift their value focus to product and service design and aim to have a positive impact on society rather than only focusing on monetary shareholder value. The sustainability strategy is referred to as the "Triple bottom line" (TBL) approach and consists of three pillars: people (social), profit (economic), and planet (environmental), also referred to as the 3 Ps (Elkington, 1994).

Scientific literature claims that despite the need to pursue all three dimensions of sustainability at the same time, companies fear that they will lose some economic success to gain environmental and social sustainability (Esfahbodi, Zhang, & Watson, 2016). However, other scholars argue that all three dimensions of sustainability can be reached without a trade-off: "The triple bottom line doesn't inherently value societal and environmental impact at the expense of financial profitability. Instead, many companies have reaped financial benefits by committing to sustainable business practices" (Miller, 2020). In other words, by focusing not only on monetary value creation but rather on an all-three-pillar approach, companies sustain their operations, mitigate risks, be inspired for innovation, become more attractive, and gain a competitive advantage (Chladek, 2019). The trilateral sustainability framework that was once a source of competitive advantage has now become a necessity in light of the Paris Agreement on Climate Change from 2015 and more recently new regulatory developments such as the European Union's Corporate Sustainability Reporting Directive (EU CSRD). This means we fundamentally need to rethink our definitions of value and cost.

Conclusively, all pillars must remain in balance for a company to be sustainable.

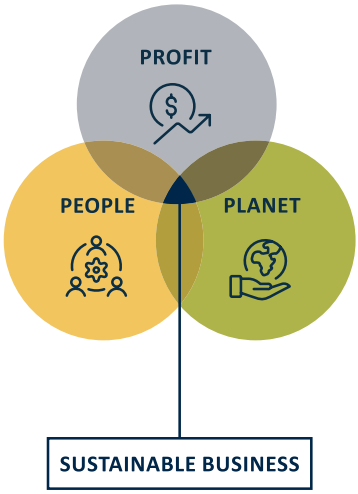


Figure 4: The three pillars of sustainability

ECONOMIC

- Profit, efficiency and productivity, turnover rate, and market performance, but also agility, risk resilience and competitiveness
- Being economically healthy ensures long-term investment and production capabilities, but attract investors and provide a stable workplace

ECOLOGICAL

- Waste, resource consumption and efficiency, CO2, emissions, pollution, and other impacts on the environment

SOCIAL

- People's welfare, ethics, compliance with the law, brand image and quality of life
- Fair working conditions and treatments for their employees but also for all other employees along their value-chain

Figure 5: The three pillars of sustainability explained

2.2.1 THE LACK OF PROGRESS IN SUSTAINABILITY

Despite the introduction of sustainable development by the Brundtland Commission in 1987 and the SDGs in 2015, there has been insufficient progress due to the lack of commitment and consequently action by governments and businesses. While two-thirds of executives think sustainability should be integrated into their company's business strategy, only 38% report that sustainability is integrated into their strategy (Soonieus, Young, Breeden, Hanson, & Tatar, 2023). For example, instead of a 43% reduction in greenhouse gases (GHG) by 2023, they increased by 14%, making it impossible to limit the 1.5-degree temperature increase to pre-industrial levels (United Nations, 2022). Biermann et al., (2022) conclude that there has been little change to the way companies operate: A lack of governmental policies, budget allocations, and a lack of change in management styles create little incentive for people and corporations to change. In 2023, the **EU Corporate Sustainability Reporting Directive (CSRD)** came into force, forcing companies to disclose previously unreported metrics on social and environmental sustainability, which in turn will create pressure to engage more in sustainable business practices.

> **Logistics companies must start making progress towards sustainability as there is a growing demand for sustainable practices from both consumers and clients, but also pressure from regulatory bodies.**

2.3 THE EFFECT OF INDUSTRY 4.0 ON SUSTAINABILITY

With the increased need to act more sustainably and at the same time facing several threats in the logistics sector, Industry 4.0 technologies (I4T) are believed to support companies in the transition. (Bau, Dallasega, Orzes, & Sarkis, 2020) explains that many managers expect that implementation of Industry 4.0 technology can bring economic growth while at the same time adhering to their sustainability strategy. They believe that technologies like AI, big data, cloud, and sensor technology yield the highest environmental benefits through providing intelligence to production processes, rationalizing the use of water, energy, and materials, and thus, reducing waste and CO2 emissions (Reis, et al., 2021).

Particularly in downstream areas of supply-chain such as warehouse and order fulfillment, which is more consumer-facing than manufacturing, technologies like automated storage and transport, robot-piece picking or artificial intelligence (AI) can overcome current challenges such as higher customer expectations, next-day delivery, order tracking, increased (network) collaboration, agile pricing, and service quality (Tipping & Kauschke, 2016). Ghobakhloo, Iranmanesh, Grybauskas, Vilkas, & Petraitė (2021) found digital transformation enables sustainable innovation: improved collaboration and knowledge sharing leading to sustainable partnerships, increased green absorptive capacity to enhance environmental-friendly process innovation, and the ability to manufacture economic and eco-friendly products. On the social dimension, (Dekhne, Hastings, Murnane, & Neuhaus, 2019) reason that automation can reduce the challenge of labor shortage, especially in peak seasons by facilitating or substituting work. Some scholars (Erol, 2016) even propose that only those companies that integrate Industry 4.0 technologies in their production system will be competitive in the long run. In other words, companies can no longer ignore adapting their operations to environmental standards. However, having a sustainability strategy alone is not sufficient: it needs to be integrated into the company's processes and decision-making.

2.4 BRIDGING INDUSTRY 4.0 AND SUSTAINABILITY: NAVIGATING IMPACTS AND TRENDS

This whitepaper explores the synergy between Industry 4.0 technologies and sustainability in logistics. Addressing key questions, it offers insights into real-world impacts and strategic choices in this evolving landscape:

1. UNVEILING INDUSTRY 4.0'S REAL IMPACT:

- Does Industry 4.0 solve all problems? We assess realities beyond assumptions by analyzing practical outcomes post-implementation.
- Is Industry 4.0's impact positive, neutral, or negative on each sustainability aspect? We bridge academia and practice to provide evidence-based insights.

2. GUIDING SUSTAINABLE DECISION-MAKING:

- How can we factor economic, environmental, and social values into investme decisions? We demystify this complex process, guiding holistic evaluations.

3. MAPPING INDUSTRY 4.0 IN LOGISTICS:

- Which Industry 4.0 technologies thrive in logistics? Our examination uncovers trends and lessons from technology deployment.

4. SHAPING FUTURE STRATEGIES AND TRENDS:

- What strategic decisions lie ahead? We illuminate the path with forward-looking trends, aiding organizations in proactive planning.

3 PRACTITIONERS INTERVIEWS: LEARNING FROM CASE STUDIES

To elaborate on the role of Industry 4.0 technologies on the sustainability of logistics service providers, the researcher interviewed industry practitioners across several companies and countries.

"How will different Industry 4.0 technologies impact the economic, environmental, and social sustainability of logistic service providers?"

THE INTERVIEWS FOCUSED ON UNDERSTANDING:

- What Industry 4.0 means in the LSP context?
- What sustainability means in the LSP context?
- The importance of Industry 4.0 technology for the sustainability of companies in the LSP context?
- How to incorporate sustainability in an Industry 4.0 business case context?
- How to incorporate Industry 4.0 technology in the sustainability strategy of an LSP company?
- What future research is needed to advance Industry 4.0 technologies in SCM?

3.1 THE EFFECT OF INDUSTRY 4.0 TECHNOLOGIES ON SUSTAINABILITY

3.1.1 ECONOMIC SUSTAINABILITY

I4.0T generally yields a net positive impact on economic sustainability, although it is not always uniformly beneficial.

One of the key benefits of I4.0T can be the lower total cost of ownership (TCO) that it delivers over time. This is because innovative solutions often involve the use of new technologies and processes that can reduce costs and improve efficiencies. Additionally, I4.0T can bring stability and predictability to costs, enabling businesses to plan and budget more effectively. Moreover, I4.0T allows for the creation of improved processes, streamlining operations, and driving greater efficiencies. Embracing I4.0T is, therefore, key to achieving economic sustainability and ensuring long-term success for businesses.

Return on investment (ROI) remains the primary decision-making factor for investment projects. While a business needs to ensure adequate cash flows and positive income to sustain, it needs to start including stakeholders, rather than shareholders. By *shifting its value proposition to make a positive impact on society, such as employees, customers, and consumers, rather than monetary shareholder value, LSP can start capturing its true value and satisfy everyone involved to create a fairer world (see also The Stakeholder shift).*

— ON THE ONE SIDE...

- Set-up investments for automated solutions are significantly higher than for manual solutions.
- Running costs, such as electricity and maintenance, are higher.
- Planning takes more effort (strategy, money, and time).

+ ON THE OTHER SIDE...

- Reduction in FTE cost.
- Reduction in space is possible which leads to fewer infrastructure costs such as rent.
- Higher economic activity due to higher efficiency, process optimization, and fewer errors.
- Resilience: the ability to deal with uncertainty such as an increase in salary costs or non-availability of employees.

EXAMPLES FROM THE PRACTITIONERS

> **→ Automated-storage-retrieval systems (ASRS) provide 4 to 5 times higher storage capacity than conventional storage solutions.**
>
> **→ Using big data/AI/Machine-learning, driving, and picking routes are planned optimally, making the process faster.**
>
> **→ The digital control tower for workflow management in order picking.**

3.1.2 ENVIRONMENTAL SUSTAINABILITY

I4.0T has an unpredictable impact on environmental sustainability, depending on the scope and type of technology as well as the specific ecological indicator analyzed.

I4.0T plays a problematic role in driving environmental sustainability because the extent to which it can contribute depends on the scope and type of technology used as well as the specific ecological indicator under consideration. This means it might have a positive or even negative effect on the environmental sustainability of companies. Practitioners are generally more optimistic about the potential of software technology compared to hardware technology, as the latter tends to consume more resources and produce higher levels of CO2 emissions upstream. It is important to consider the negative externalities associated with I4.0T, such as depleting scarce resources and producing additional waste. Therefore, a life-cycle assessment of the entire production-usage-waste of I4.0T is necessary to accurately compare it to the alternative. By conducting a comprehensive analysis, businesses can identify opportunities to reduce their environmental impact while still benefiting from I4.0T.

Environmental sustainability has risen in importance in strategic decision-making but *only plays a decisive role when solutions have a similar economic impact or are long-term planning projects such as buildings.*

— ON THE ONE SIDE...

- More virgin material consumption and production (such as metals and steel) increases (upstream).
- Local energy consumption goes up and produces more CO2 emissions if it is not produced with green energy.
- Better processes/increases throughput leads to more consumerism (rebound effect paradox).

+ ON THE OTHER SIDE...

- Efficiency downstream increases.
- Less CO2 production caused by businesses through higher resource efficiency .
- Resources are used more efficiently/less waste through intelligent decision-making.
- Enables new services (circular economy services such as reselling) which can reduce resource consumption.
- Data tracking of products in the SC enables more transparency into environmental behavior.

EXAMPLES FROM THE PRACTITIONERS

> → **ASRS does not require light to operate and generates heat which leads to less electricity and gas needed for heating. For example in Hamm, the shuttle heats the warehouse halls during winter, while during summer the heat is sent outside the building, decreasing the need for a ventilation system.**
>
> → **On-demand packaging optimizes the carton size, leading to a ca 40% higher density of parcels per pallet or truck, leading to less air volume shipped and less pollution by fewer trucks needed.**
>
> → **Using the Customer Experience Cloud (CXC) diminishes the need for paper and toner during the return processes, saving trees, water, and energy in paper production.**
>
> → **Using big-data/AI/Machine-learning, driving, and picking routes are planned optimally, reducing the total KM driven and thus, reducing emissions.**

3.1.3 SOCIAL SUSTAINABILITY

I4.0T generates a net positive impact on social sustainability by benefiting diverse stakeholders across various domains.

I4.0T is a powerful tool for driving social sustainability, offering numerous benefits that can positively impact businesses and society at large. By embracing innovative technologies, businesses can improve their brand image and attract and retain B2B partners. Additionally, I4.0T can help address demographic shifts in social problems, such as the lack of interest in jobs in the logistics sector. However, upskilling workers and upskilling workstations are essential to ensure that they have the skills and opportunities necessary to succeed in a rapidly changing environment. Further, companies need to ensure that they are not shifting problems geographically, such as upstream mineral sourcing or production.

While I4.0T has numerous social benefits for all stakeholders, social sustainability is hardly considered when making investment decisions despite its direct impact on the business stakeholders, such as its clients and employees.

— ON THE ONE SIDE...

- Increases the need for upskilled employees and the thus effort for training.
- This can be perceived as taking jobs away or making it more difficult.
- Unfavorable work times as technology can work 24/7 and needs supervision.
- A geographic shift in problems (upstream production).

+ ON THE OTHER SIDE...

- Positive impact on brand image "innovative & forward-looking".
- Customer and employee attraction.
- Higher shareholder evaluation.
- Attractive workplace (less repetitive, non-ergonomic tasks or less time in hazardous environments).
- More insights & transparency for LLP, customer, and consumer.

EXAMPLES FROM THE PRACTITIONERS

> **→ Sensors, RFID tags, and IT systems to track the order through every step from order placement to delivery and return increasing transparency for customers and consumers.**
>
> **→ The cloud-based, standardized IT system provides global insights, is easy to scale to new locations, processes can be proactively driven and data harmonized, creating a lean process.**
>
> **→ Robot arms to pick and (de)palletize heavy boxes or in loose-loaded and hot containers (*see the example of "Stark"*).**
>
> **→ AGVs to move pallets, and trash bins or scrub the floor.**
>
> **→ AI/ML to send a timeframe of 2h instead of 8h to customers when a parcel will be delivered.**

3.2 THE TRADE-OFF SITUATION

ASRS

400 % more storage VS Upstream material consumption

ASRS: While LSP can store 400% more space within the same space as with conventional solutions, ecological resource consumption such as metals, oils, and electricity increases significantly.

ON-DEMAND PACKAGING

Upstream resources VS downstream truck efficiency (40 %)

On-demand packaging: Whereas upstream manufacturers bare investments into right-size packaging technologies, downstream last-mile deliverers can save 40% in truck space, thus reducing their costs and CO2 footprint.

AI / ML

75 % reduction in parcel waiting time VS electricity consumption

AI / ML: Through delivery time prediction, consumers' waiting time is reduced by 75% whereas data centres' electricity consumption goes up.

ROBOT/EXOSKELETON

Financial costs VS employee happiness

Robot/exoskeleton: LSP need to bear financial costs for lifting/picking devices whereas employees' work is facilitated and their health is protected.

Figure 6: Trade off examples

3.3 CHALLENGES OF PRACTITIONERS WITH I4.0T IMPLEMENTATION

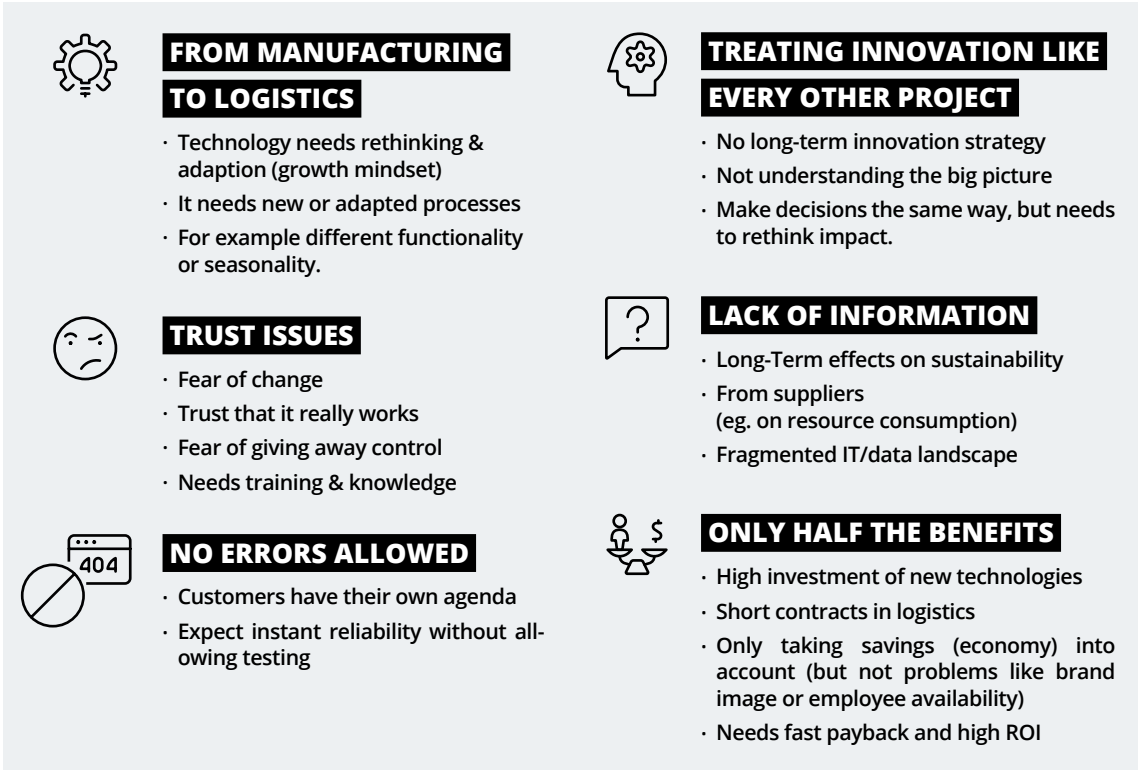


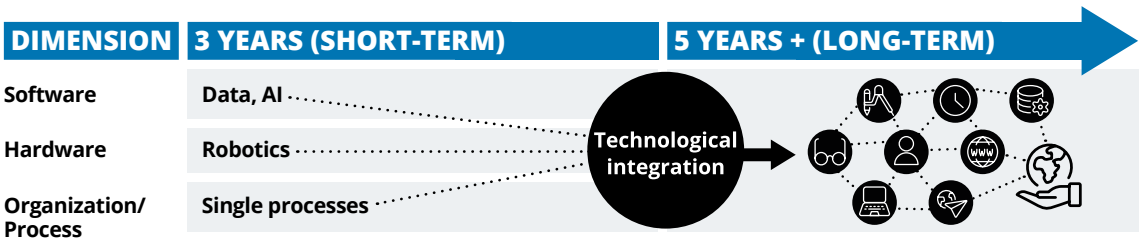
Figure 7: Challenges of I4.0T implementation

4 FUTURE OUTLOOK: INDUSTRY 4.0 TECHNOLOGY & SUSTAINABILITY

As businesses consider the adoption of Industry 4.0 technologies in logistics, it is important to recognize that many of these technologies are new to the field. While some technologies have been successfully implemented in manufacturing, there may be a learning curve when applying them to downstream warehousing and order fulfillment centers. It is important to allow time for adjustment, and experimentation, and to give technologies the freedom to make mistakes. Additionally, it may take time for employees to fully accept these technologies as new co-workers, even if they are curious. Without change management, strategy adaptation, and a cultural change to embrace new technologies, the implementation of Industry 4.0 technologies in logistics is unlikely to succeed; but by adopting these approaches, businesses can unlock the full potential of these advanced technologies and gain a competitive advantage in the marketplace.

> **Industry 4.0 technology can have a net positive impact on economic and social sustainability, but an unpredictive impact on environmental sustainability. Only (!) by gaining an understanding of the total impact of a new technology, we can understand the true value of technology.**

4.1.1 INNOVATION PIPELINE IN THE FUTURE



DIMENSION	3 YEARS (SHORT-TERM)	5 YEARS + (LONG-TERM)
Software	· Technologies: Big data / real-time analytics; cloud computing; AI → Gaining insights for decision-making; (self-) improvement or preventive maintenance	· Technologies: AI, IoT with sensors, big data → Interconnectivity of systems & processes; increased transparency
Hardware	· Technologies: Robotics (AGV, robot arms) in combination with AI → Cyber-physical-system → Automation of manual processes; adding intelligence to machines & processes	· Existing technologies/industry 3.0 technologies in new environments → Adaptability & environmental awareness
Organization / Process	· Understand the total impact of investment decisions · Organisational readiness (overcome challenges; improve existing technologies)	· Holistic view on logistics instead of single processes · Making decisions based on a multi-balanced scorecard instead of only ROI

Figure 8: Short-term vs. long-term strategic outline

5 CONCLUSION

5.1 A TRADE-OFF SITUATION?

Supply-chain companies must balance rising pressure to be competitive and become more sustainable while handling increasing order volume. The lack of progress, rising awareness, the introduction of governmental policies like CSRD, and the resistance to change human behaviors force companies to adopt a wider perspective. I4.0T might be a way to deal with sustainability ambitions but it will not be easy to develop a right corporate strategy that can tick all the boxes without any trade-offs. Although Industry 4.0 technology can have a net positive impact on economic and social sustainability, it might have a positive or even negative on the environmental sustainability of companies. While ROI demands in the sector are changing, mainly due to labor shortages, decision-makers still mostly only consider financial impact when making decisions.

This research has focused on the impact of Industry 4.0 technologies on the economic, ecological, and social sustainability of logistics service providers in warehousing and order fulfillment. Results show that the true value and cost of an Industry 4.0 technology differs depending on the position in the supply chain and the technology.

5.2 CALL TO ACTION: THE IMPORTANCE OF INDUSTRY 4.0 TECHNOLOGY

Overall, Industry 4.0 technologies can help LSP overcome market disruptions:

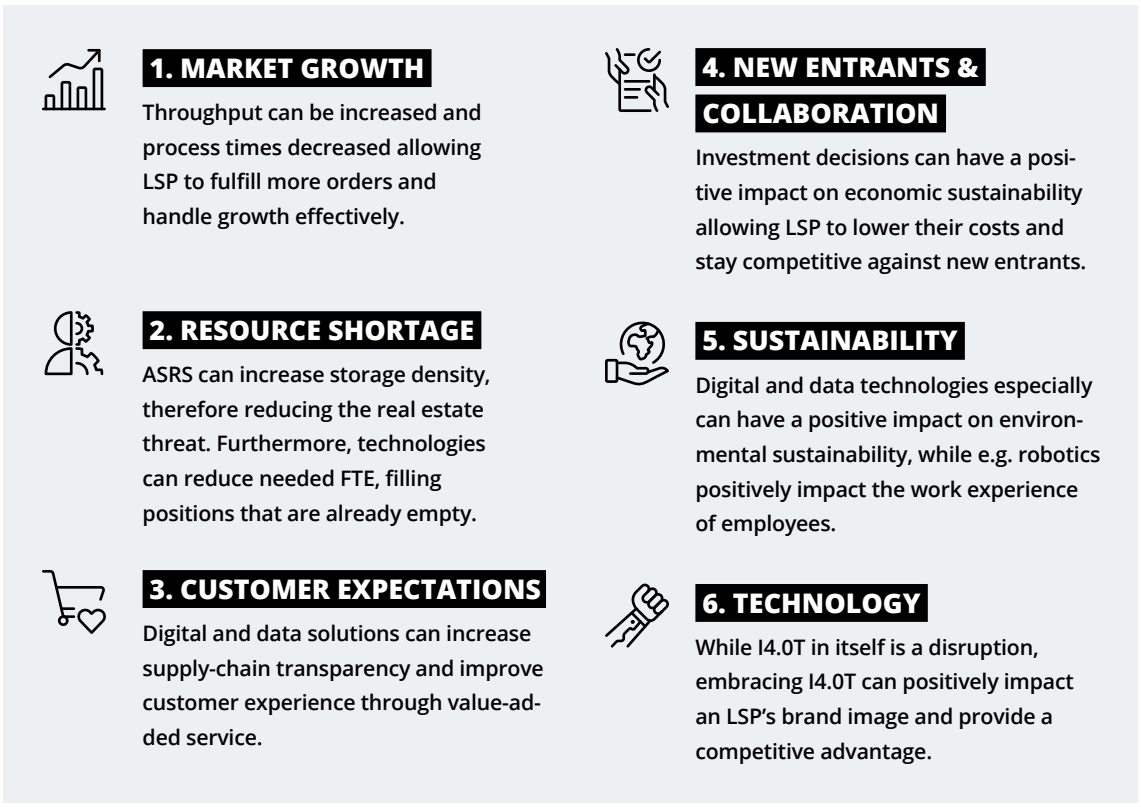


Figure 9: How I4.0T can help overcoming challenges in logistics

While these advanced technologies hold immense potential for financial gains, it is crucial to emphasize that decision-makers must adopt a comprehensive approach that considers the overall impact on all stakeholders. Industry practitioners have highlighted the imperative for LSPs to proactively incorporate current trends and disruptions into their decision-making processes, as failure to do so may result in a significant risk of falling behind and facing adverse disadvantages.

"Current problems are not acute (painful) enough to take them into account when making decisions."

Senior Expert Logistics Engineering

We must question why we continue to do things the way they've always been done. In many cases, this approach is hindering progress and stands in the way of I4.0T. By embracing change management and being open to new ways of doing things, we can position ourselves for success in an ever-evolving business landscape.

"Change management: Why change the way it always has been done? Now, the way it has always been done is standing in the way of change."

Corporate Sustainability Manager

"It's time to break free from the limitations of the past. Let's adopt a visionary approach to decision-making that looks beyond our walls and positions us for success in a constantly evolving business landscape."

Karoline Kowalik,
Author and Logistics Engineer at Arvato

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ABOUT THE AUTHOR

Karoline Kowalik is a Logistics Engineer and PhD researcher at Arvato and Maastricht University. She mainly focuses on I4.0T projects such as robotics and sustainability. Her research focuses on the interplay and evaluation of innovation, sustainability, and green decision-making.

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7 APPENDIX

7.1 INNOVATION 4.0 TECHNOLOGIES

ADDITIVE MANUFACTURING (3D PRINTING)

- Additive manufacturing, also known as 3D printing, is a process that creates products by building up sequential layers of materials.

ADVANCED ROBOTICA

- Advanced robotics, such as autonomous vehicles or picking robots, are equipped with AI, sensors, cameras, radars, computer and connected via the cloud.

AUGMENTED / VIRTUAL REALITY

- AR takes the capabilities of computer-generated display, sound, text, and effects to enhance the user's real-world experience through wearable equipment.

BLOCKCHAIN

- A blockchain is basically a database of records (i.e., all transactions or digital events that have been executed) that is distributed and shared among participating parties.

CLOUD AND BIG DATA

- The cloud refers to the on-demand availability of computer system resources, such as data storage or computing power, of a remote network. Big data analytics represent the ability to acquire knowledge from the data with the application of statistics, mathematics, simulations, in order to make better decisions.

CYBER PHYSICAL SYSTEMS

- They are systems that blend the physical and the virtual worlds. By doing so, they construct a totally networked world, where smart objects are able to interact and communicate with each other.

INTERNET OF THINGS

- Internet of Things (IoT) creates a comprehensive network infrastructure in order to connect physical objects and virtual systems by using the Internet.

SIMULATION AND DIGITAL TWINS

- Simulation modeling is the method where models of a real or an envisioned system or process are used to better understand and predict the behavior of the modeled system or process. The concept of digital twin expands the use of simulation modeling to all phases of the product/service life cycle.

Figure 10: I4.0T explained

7.2 THE INTERVIEW QUESTIONS

The following research protocol was established, to facilitate qualitative data collection during interviews. Not to disclose confidential information, a simplified version is here provided.

The aim of this interview is …

- **to understand what Industry 4.0 in the logistics context.**
- **to understand what sustainability is in the logistics context.**
- **to determine the importance of Industry 4.0 technology in the sustainability context.**
- **how to incorporate sustainability in an Industry 4.0 business case context.**
- **what future research is needed to advance Industry 4.0 in logistics.**

I. GENERAL QUESTIONS ABOUT THE POSITION

- Who you are (position, experience on the field) and what is your role in the company?
- How much does your position relate to Innovation 4.0 and/or sustainability?

II. EXPLORATORY QUESTIONS ABOUT THE I4.0T & SUSTAINABILITY

1. I4.0T:
   a. What is I4.0T to you in a business context?
   b. The I4.0T project undertaken by you/ your company (high-level)?
   c. The scope + technologies used in/of these projects?
   d. The motivation used behind the decision to undertake such a project?
2. Sustainability:
   a. What is sustainability to you in a business context?
   b. How did you consider these things when making a business case?

III. THE ROLE OF I4.0T IN SUSTAINABILITY

1. What is the (positive and negative) impact on economic sustainability? Example?
2. What is the (positive and negative) impact on environmental sustainability? Example?
3. What is the (positive and negative) impact on social sustainability? Example?
4. What challenges you expect/have experienced hinder realizing the beforementioned benefits?

IV. FUTURE RESEARCH

1. What I4.0 technologies do you expect to be important in the short-term (<3 years) and longer-term?
2. Which effects of I4.0T on sustainability are unclear and need further research / will help you?

INTERVIEWEE NUMBER	POSITION	YEARS OF EXPERIENCE	LOCATION	PROJECTS (EXAMPLE)
1	Manager Automation and Implementation	15 years	The Netherlands	Warehouse innovation (ASRS)
2	Expert Innovation in Logistics Engineering	13 years	Germany	Warehouse innovation (smart packaging)
3	Corporate Sustainability Manager	13 years	US	Sustainable governance and infrastructure
4	Vice President Future Warehouse	30 years	Germany	Warehouse innovation (robotics, AGV, strategy)
5	Manager Operations and Innovation	6.5 years	The Netherlands	Automation and network design
6	Senior Expert Logistics Engineering	15 years	Germany	Warehouse innovation (AGV)

Table 1: Description of interviewees

8 REFERENCES

Bau, C., Dallasega, P., Orzes, G., & Sarkis, G. (2020). Industry 4.0 technologies assessment: A sustainability perspective. *International Journal of Production Economics.*

Biermann et al. (2022). Scientific evidence on the political impact of the Sustainable Development Goals. *Nature Sustainability,* 795 - 800.

CBRE. (2023, January 26). Logistics - Market Insights 2023. Retrieved from CBRE: https://real-estate-outlook.cbre.nl/2023-report-en/logistics

Chevalier, S. (2022, July). *Retail e-commerce sales worldwide from 2014 to 2026.* Retrieved from Statista: https://www.statista.com/statistics/379046/worldwide-retail-e-commerce-sales/

Chladek, N. (2019, November 06). *WHY YOU NEED SUSTAINABILITY IN YOUR BUSINESS STRATEGY.* Retrieved from Harvard Business School: https://online.hbs.edu/blog/post/business-sustainability-strategies

Clement, J. (2020, March 19). *Global retail e-commerce sales 2014-2023.* Retrieved from Statista: https://www.statista.com/statistics/379046/worldwide-retail-e-commerce-sales/

Convey. (2021). *Expert Insights: 2021 Trends in Retail & eCommerce.* Convey.

Dekhne, A., Hastings, G., Murnane, J., & Neuhaus, F. (2019, April 24). Automation in logistics: *Big opportunity, bigger uncertainty.* Retrieved from McKinsey & Company: Travel, Logistics & Infrastructure: https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/automation-in-logistics-big-opportunity-bigger-uncertainty

DHL. (n.d.). *THE DEEPENING TALENT SHORTAGE.* Retrieved from DHL Supply Chain Insights: https://www.dhl.com/nl-en/home/our-divisions/supply-chain/thought-leadership/articles/the-deepening-talent-shortage.html

Efthymiou, O. K., & Ponis, S. T. (2021). Industry 4.0 Technologies and Their Impact in Contemporary Logistics: A Systematic Literature Review. *Sustainability.*

Elkington, J. (1994). Enter the Triple Bottom Line. In J. Elkington, *Triple Bottom Line* (pp. 1-16).

Ellen MacArthur Foundation. (n.d.). *What is circular economy?* Retrieved from Circular Economy Introduction: https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview

Erol, S. (2016). Where is the Green in Industry 4.0? or How Information Systems can play a role in creating Intelligent and Sustainable Production Systems of the Future. *First Workshop on Green (Responsible, Ethical, Social/Sustainable) IT and IS – the Corporate Perspective (GRES-IT/IS).* Vienna: WU Vienna.

Esfahbodi, A., Zhang, Y., & Watson, G. (2016). Sustainable supply chain management in emerging economies: trade-offs between environmental and cost performance. *Int. J. Prod. Econ,* 350-366.

European Commission. (2021, July 14). *Climate strategies & target.* Retrieved from European Commission Website: https://ec.europa.eu/clima/policies/strategies_en

European Commission. (2023). *Corporate sustainability reporting.* Retrieved from European Commission - Finance: https://finance.ec.europa.eu/capital-markets-union-and-financial-markets/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en

Ghobakhloo, M., Iranmanesh, M., Grybauskas, A., Vilkas, M., & Petraitė, M. (2021). Industry 4.0, innovation, and sustainable development: A systematic review and a roadmap to sustainable innovation. *Business Strategy and the Environment,* 4237 - 4257.

Hermann, M., Pentek, T., & Otto, B. (2016). Design principles for industrie 4.0 scenarios. *49th Hawaii International Conference on IEEE System Sciences (HICSS).* Koloa, HI, USA.

Intelligence Group. (2019, November 5). *Dutch labor market shortages growing challenge for employers.* Retrieved from News & blogs Intelligence Group: https://intelligence-group.nl/en/news/dutch-labour-market-shortages-growing-challenge-for-employers

Kamer, L. (2020, January 27). *Number of new companies in the transport and logistics sector in the Netherlands from the 1st quarter of 2018 to the 1st quarter of 2019, bu industry.* Retrieved from Statista: https://www.statista.com/statistics/897645/number-of-new-companies-in-the-transport-and-logistics-sector-in-the-netherlands-by-industry/

Kang, S. S., Lee, J. Y., Choi, S., Kim, H., Park, J. H., Son, J. Y., & Noh, S. D. (2015). Smart Manufacturing: Past Research, Present Findings, and Future Directions. *INTERNATIONAL JOURNAL OF PRECISION ENGINEERING AND MANUFACTURING-GREEN TECHNOLOGY,* 111 - 128.

Lasi, H., Fettke, P., Kemper, H. G., Feld, T., & Hoffmann, M. (2014). Industry 4.0. *Business & Information Systems Engineering,* 239 - 242.

Liao, Y., Deschamps, F., Loures, E., & Ramos, L. F. (2017). Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal. *International Journal of Production Research.*

Miller, K. (2020, December 8). *THE TRIPLE BOTTOM LINE: WHAT IT IS & WHY IT'S IMPORTANT.* Retrieved from Harvard Business School Online: https://online.hbs.edu/blog/post/what-is-the-triple-bottom-line

Moshood, T. D., & Sorooshian, S. (2021). The Physical Internet: A means towards achieving global logistics sustainability. *Open Engineering.*

Nagy, J., Oláh, J., Erdei, E., Erdei, E., Máté, D., & Popp, J. (2018). The role and impact of industry 4.0 and the Internet of Things on the business strategy of the value chain-the case of Hungary. *Sustainability (Switzerland).*

Nantee, N., & Sureeyatanapas, P. (2021). The impact of Logistics 4.0 on corporate sustainability: a performance assessment of automated warehouse operations. *Benchmarking.*

Nguyen, T., Duong, Q. H., Nguyen, T. V., Zhu, Y., & Zhou, L. (2022). Knowledge mapping of digital twin and physical internet in Supply Chain Management: A systematic literature review. *International Journal of Production Economics.*

Onstein, S., Visser, J. G., Tavasszy, L., & van Ham, H. (2016). Trends in distribution centres and their locations: sprawl and polarization. *23rd Colloquium Vervoerslogistieke Werkdagen.* Mechelen, Belgium.

Pemberton, C. (2018). *Key Findings From the Gartner Customer Experience Survey.* Gartner.

Pfohl, H. C., Yahsi, B., & Kurnaz, T. (2015). The Impact of Industry 4.0 on the Supply Chain. *Proceedings of the Hamburg International Conference of Logistics (HICL)* (pp. 31 - 58). Hamburg: epubli GmbH.

Reis, J., Espuny, M., Nunhes, T., Sampaio, N., Isaksson, R., Campos, F., & Oliveira, O. (2021). Striding towards Sustainability: A Framework to Overcome. *Sustainability.*

Schmidt, R., Moehring, M., Haerting, R., Recihstein, C., Neumaier, P., & Jozinovic, P. (2015). Industry 4.0 - Potential for Creating Smart Products: Empirical Research Results. *International Conference on Business Information Systems,* (pp. 16-27).

Sniderman, B., Mahto, M., & Cotteleer, M. (2016, February 23). *Industry 4.0 and manufacturing ecosystems - Exploring the world of connected enterprises.* Retrieved from Deloitte Insights: https://www2.deloitte.com/us/en/insights/focus/industry-4-0/manufacturing-ecosystems-exploring-world-connected-enterprises.html

Tipping, A., & Kauschke, P. (2016). *Shifting patterns: the future of the logistics industry.* Retrieved from PWC Documents.

Tjahjono, B., Esplugues, C., Ares, E., & Pelaez, G. (2017). What does Industry 4.0 mean to Supply Chain. *Manufacturing Engineering Society International Conference,* (pp. 1175 - 1182).

Torn, I. A., & Vaneker, T. (2019). Mass Personalization with Industry 4.0 by SMEs: a concept for collaborative networks. *International Conference on Changeable, Agile, Reconfigurable and Virtual Production* (pp. 135-141). Elsevier.

Umar, M., Khan, S. A., Zia-ul-haq, H. M., Yusliza, M. Y., & Farooq, K. (2022). The role of emerging technologies in implementing green practices to achieve sustainable operations. *TQM Journal.*

United Nations. (2022). *The Sustainable Development Goals Report.* Department of Economic and Social Affairs.

United Nations. (n.d.). *Transforming our world: the 2030 Agenda for Sustainable Development.* Retrieved from UN Department of Economic and Social Affairs: Sustainable Development: https://sdgs.un.org/2030agenda

Wood, J. (2022, March 18). *Shaping the Future of Consumption and Shaping the Future of Consumption.* Retrieved from World Economic Forum: https://www.weforum.org/agenda/2022/03/generation-z-sustainability-lifestyle-buying-decisions/

Zhou, K., Liu, T., & Zhou, L. (2015). Industry 4.0: Towards Future Industrial Opportunities and Challenges. *12th International Conference on Fuzzy Systems and Knowledge Discovery,* (pp. 2147 - 2152).

REFERENCES IMAGES

Dmitry. stock.adobe.com

Dyageleva. stock.adobe.com

Kittiphat. stock.adobe.com

morepiixel. stock.adobe.com

ND STOCK. stock.adobe.com

Oulaphone. stock.adobe.com

pickup. stock.adobe.com

Planetz. stock.adobe.com

Renata Hamuda. stock.adobe.com

Sasint. stock.adobe.com

Vladimir. stock.adobe.com