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MASTER THESIS

Technology-Driven Strategies for ESG Risk Management in Purchasing and Supply Management

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ABSTRACT

The increasing regulatory focus on Environmental, Social and Governance (ESG) issues has led to new requirements for organisations, particularly under the Corporate Sustainability Due Diligence Directive (CSDDD). This directive requires organisations to integrate due diligence requirements into their corporate policies, addressing human rights and environmental impacts while maintaining transparency, public communication, and establishing a complaint mechanism, while holding organisations legally accountable not only for their own actions, but also for violations occurring within their supply chains. While it represents a significant step towards increased sustainability in the field of Purchasing and Supply Management (PSM), organisations face several challenges in implementing and complying with the CSDDD, especially in gaining supply chain transparency. This research focuses on various (Industry 4.0) technology solutions and their potential to support organisations in effectively managing ESG risks, improving regulatory compliance and ensuring future readiness. The research has been conducted through semi-structured interviews with both technology solution providers and PSM experts/buyers, and has been supplemented by web-based research to assess and verify available technology solutions. The results indicate that both technology solution providers and organisations emphasise (ESG) risk management, advanced technology usage, and (future) compliance, although to a varying degree. The research highlights the importance of compliance with new regulations, the wide range of technology solutions for ESG risk management and their limitations, the importance of collaboration among technology suppliers and the expected convergence of technology solutions in the future for delivering a broader range of capabilities to obligated organisations.

Keywords: ESG, CSDDD, regulations, purchasing, supply management, risk management, technology solutions, Industry 4.0

TABLE OF CONTENTS

INDEX OF TABLES

INDEX OF FIGURES

INDEX OF ABBREVIATIONS

AI	Artificial Intelligence
AM	Additive Manufacturing
AR	Augmented Reality
CBAM	Carbon Border Adjustment Mechanism
CPPS	Cyber-Physical Production Systems
CPS	Cyber-Physical Systems
CSDDD	Corporate Sustainability due Diligence Directive
CSR	Corporate Social Responsibility
CSRD	Corporate Sustainability Reporting Directive
DTs	Digital Twins
ESG	Environmental, Social, Governance
ERP	Enterprise Resource Planning
EU	European Union
I-IoT	Industrial Internet of Things
IoT	Internet of Things
I4.0	Industry 4.0
LkSG	Lieferkettensorgfaltspflichtengesetz
M&A	Mergers and Acquisitions
ML	Machine Learning
NEVI	Nederlandse Vereniging voor Inkoopmanagement/Dutch Association for Purchasing and Supply Management
OECD	Organisation for Economic Co-operation and Development
PSM	Purchasing and Supply Management
RFID	Radio-Frequency Identification
RPA	Robotic Process Automation
SMEs	Small and Medium-sized Enterprises
UN	United Nations

1. INTRODUCTION: TECHNOLOGY AS ANTECEDENCE OF ESG RISK MANAGEMENT IN SUPPLY CHAINS

1.1 Addressing ESG risks in supply chains: A funnel model on the impact of EU requirements and evolving risks

The supply chain landscape is undergoing a significant change driven by evolving Environmental, Social, and Governance (ESG) regulations, particularly those developed by the European Union (EU). The EU's strict ESG guidelines guide organisations towards sustainable practices within their operations and across supply chains. However, the introduction of mandatory regulations, including the Corporate Sustainability due Diligence Directive (CSDDD), increases uncertainties and risks in the field of Purchasing and Supply Management (PSM).

The CSDDD, which is the main focus in this research, requires organisations to integrate due diligence into their corporate policies and supply chains to identify, prevent, and mitigate potential and actual adverse impacts on human rights and the environment.[1] However, supply chains are often long and complex, making it difficult to create transparency beyond tier-1 suppliers.[2] This lack of transparency can lead to uncertainties about sustainability-related misconduct upstream the supply base, where oversight is weaker and the cost and complexity of gathering information increases.[3] Furthermore, regular monitoring of suppliers for compliance with human rights and environmental standards adds further operational burdens, including increased costs due potential reductions in suppliers and supply chain bottlenecks[4]. In addition, failure to adhere to the CSDDD can lead to penalties, creating additional uncertainties and risks for organisations.[5]

Therefore, organisations operating within the scope of the CSDDD need to ensure robust compliance mechanisms and resilient risk management strategies. To address these challenges, technologies, particularly Industry 4.0 (I4.0) solutions, are increasingly important to increase supply chain transparency and improve risk management.

1.2 Embedding the research in the academic and practical domain

This research is based on both academic theory and practical application. The research focuses on how I4.0 technologies can improve ESG risk management in the field of PSM.

[1] See European Parliament and Council of the European Union (2024), p. 9.
[2] See Foerstl et al. (2018), p. 215; van Hoek et al. (2020), p. 6.
[3] See Dai and Tang (2022), p. 7.
[4] See Felbermayr et al. (2022), p. 47.
[5] See Shafiq et al. (2017), p. 1389; Felbermayr et al. (2021), p. 14.

The pyramid model developed by Schiele et al. (2021, p. 56), describing the classification of supply risks in the field of PSM, has been used as guiding framework. Building upon the classification, the model created by Hallikas et al. (2004, p. 52); Hoffmann et al. (2013, p. 199) has been used in this research, which outlines a structured approach to risk management that includes risk identification, assessment, management and monitoring.

Furthermore, this research focuses on the potential of advanced technologies and technology solutions, including AI and blockchain, for supporting (ESG) risk management and compliance. For instance, these technologies can support decision-making, providing real-time insights[6] and help to achieve transparency within supply chains[7]. However, while technology solutions present opportunities for improved ESG risk management and compliance for buying organisations, their implementation faces challenges, including the limitations of the technologies itself, the need of collaboration among stakeholders[8] and the complexity of integration[9]. These perspectives emphasises the need for continued research into both the benefits and limitations of the technologies and technology solutions in the context of (ESG) risk management.

1.3 Research objectives: Investigating the use of technology to manage ESG risk

Based on the literature review, one main research question has been developed:

How can Industry 4.0 technology solutions be leveraged to effectively manage Environmental, Social, and Governance regulatory risks in the field of Purchasing and Supply Management?

From the main research question, the following sub-questions have been derived:

(1) *What are the regulatory Environmental, Social, and Governance risks prevalent in the field of Purchasing and Supply Management?*

(2) *Which (Industry 4.0) technologies are currently utilised within the field of Purchasing and Supply Management to address Environmental, Social, and Governance risks?*

(3) *To what extent are ESG considerations integrated into technology solutions within the field of Purchasing and Supply Management?*

[6] See Bienhaus and Haddud (2018), p. 978; Allal-Chérif et al. (2021), p. 75.
[7] See Kalaiarasan et al. (2022), p. 4.
[8] See Bodendorf et al. (2022), p. 801; Herold et al. (2022), p. 435.
[9] See Kopyto et al. (2020), p. 8.

(4) *To what extent do technology solutions and organisations ensure compliance with the CSDDD?*

(5) *What strategic actions and technological adaptations must organisations undertake to comply with new ESG regulations in the field of Purchasing and Supply Management?*

1.4 Methodology: Conducting interviews and web-based research to assess technology solutions and perceptions

Semi-structured interviews have been conducted to gain a better understanding of the perspectives of industry experts/buyers and technology solution providers on their integration of ESG considerations into PSM processes, the focus on ESG regulations, the role of I4.0 technologies, as well as to explore the current capabilities of technologies and their developments. Semi-structured interviews have been conducted as they provide flexibility in asking questions, which is especially useful when researching complex or open-ended topics and exploring the 'how' and 'why' behind participants' experiences and perceptions. In addition, web-based research on current technology solutions has been conducted to expand the dataset and to increase the validity and reliability of the research.

1.5 Theoretical and practical contributions: Technology solutions for ESG integration

This research makes important contributions to the understanding of technology solutions for ESG risk management and compliance with regulations, including the CSDDD. It evaluates the effectiveness of technology solutions across maturity dimensions, that include risk management, ESG integration, compliance with regulations, and future readiness, while addressing challenges such as achieving supply chain transparency.

The findings emphasise the important role of AI in identifying, assessing and monitoring risk data, while blockchain, despite its current limitations, offers potential for future integration with other technologies. It also highlights the importance of third-party data to improve data quality and insights.

From a practical perspective, the research contributes with insights for technology solution providers, showing a trend towards merging capabilities to provide comprehensive solutions. This collaboration is expected to improve regulatory compliance, risk management and overall effectiveness in addressing ESG challenges. In addition, the research provides an understanding for buying organisations by providing insight into what technology solutions are capable of and what can be expected in the future.

1.6 Structure of the paper: From ESG regulations to technology solutions

The paper is structured as follows. This literature review introduces the topics of ESG and regulations, supply risks and corresponding risk management strategies, as well as the developments of Industry 4.0 technologies, narrowing it down to the context of the field of PSM. The second section presents the methodology, in which the research design, the interview participants and the interview protocols are addressed. The third section describes the research findings. The discussion, as well as the theoretical and practical contributions are given in the fifth section. The paper concludes in the sixth section, in which the limitations, and further research contributions, are addressed.

2. THEORETICAL BACKGROUND: ESG REQUIREMENTS AS A SOURCING RISK

2.1 Evolution of ESG and its EU requirements: Initiatives and regulatory foundations in the field of Purchasing and Supply Management

2.1.1 Developing ESG requirements

In the light of increasing environmental degradation, poor corporate governance, and social inequality, adopting sustainable practices is becoming increasingly important and considered as a crucial agenda item in many organisations.[10] Several concepts have emerged that highlight this need for social, environmental, and ethical considerations in modern business practices. For instance, considerable emphasis is placed on concepts such as Corporate Social Responsibility (CSR) and Environmental, Social and Governance (ESG). In general, CSR can be considered as a tool by which organisations integrate social, environmental, and economic considerations into their values, culture, decision-making, strategy, and operations in a transparent and responsible manner. The approach aims to introduce improved practices within organisations to promote wealth creation and improve societal wellbeing, and focuses on the "how to behave ethically".[11] On the other hand, in similarity to CSR, the ESG concept is concerned with the appropriate measures of ethical performance.[12]

The "Who Cares Wins" report written by Ivo Knoepfel represents the beginning of the ESG discourse, which has been initiated by the efforts of former United Nations Secretary-General Kofi Annan in 2003. Annan, who initiated the change within the United Nations, called for collective action in a letter to 55 of the world's leading financial institutions in 2004 to strengthen the ESG discourse and integrate environmental, social, and governmental issues into corporate finance.[13]

The ESG discourse as known today focuses on various aspects and considerations, including the composition and environmentally friendly production of an organisation's products, with an increasing focus on the reduction of the carbon footprint.[14] Additionally, strategies involving the reduction of plastic usage, the utilisation of renewable energy in environmental management, regulatory compliance, human capital criteria, fair payment practices, anti-discrimination measures and the promotion of diversity and inclusion are integral components of the ESG framework.[15] In general, ESG can be defined as "a set of activity or

[10] See Wong et al. (2015), p. 5; A. Gupta et al. (2021), p. 1.
[11] See Dathe et al. (2022), p. 117.
[12] See Dai and Tang (2022), p. 3; Dathe et al. (2022), p. 117; Asif et al. (2023), pp. 1,2.
[13] See UN Global Compact (2004), p. 1; Dathe et al. (2022), p. 119.
[14] See Dathe et al. (2022), p. 118.
[15] See Dathe et al. (2022), p. 118.

processes associated with an organisation's relationship with its ecological surroundings, its coexistence and interaction with human organisms and other populations, and its corporate system of internal controls and procedures (such as processes, customs, policies, laws, rules and regulations, etc.) to direct, administer and manage all the affairs of the organisation, in order to serve the interests of stockholders and other stakeholders" [16].

While the UN Global Compact report focused on a voluntary approach, some ESG initiatives call for mandatory measures.[17] Recent developments, of which the European Union's Corporate Sustainability Reporting Directive (CSRD) and European Commission's Corporate Sustainability due Diligence Directive (CSDDD, or CS3D) are primary examples, emphasise the trend towards regulatory requirements for the integration of ESG considerations into business practices and supply chains.[18] These regulations require organisations to manage the legal requirements, particularly in the field of PSM.

2.1.2 Resulting ESG complication in Purchasing and Supply Management

The CSDDD, alongside the CSRD, plays an important role in shaping corporate sustainability. The CSDDD requires affected organisations to "integrate due diligence into their policies and risk management systems, identify and assess, where necessary prioritise, prevent and mitigate as well as bring to an end and minimise the extent of actual and potential adverse human rights and environmental impacts, provide remediation in relation to actual adverse impacts, carry out meaningful engagement with stakeholders, establish and maintain a notification mechanism and complaints procedure, monitor the effectiveness of the measures taken in accordance with the requirements […] and communicate publicly on their due diligence"[19].

Many European organisations have started to take control of their internal operations by reducing their risks, integrating sustainability into work processes, and strictly complying to health and safety regulations.[20] However, the most urgent sustainability challenges are manifested externally, particularly within the supply chain, up to the extraction of raw materials.[21] Consequently, the field of PSM has become an important factor for ensuring responsible and ethical practices, which is emphasised by the increasing emergence of strict environmental, social and governance requirements and regulations. Notably, the CSDDD,

[16] Whitelock (2015), p. 392.
[17] See Dathe et al. (2022), p. 126.
[18] See European Commission (2022); European Union (2022).
[19] European Parliament and Council of the European Union (2024), p. 9.
[20] See Aichbauer et al. (2022), p. 10.
[21] See Aichbauer et al. (2022), p. 10.

which has been adopted by the European Council on May 24, 2024, represents an important step towards improving the ethical standards in the field of PSM.

An important aspect of the CSDDD is the liability it places on organisations. Organisations will be held accountable when failing to comply with due diligence obligations regarding human rights and environmental impacts, including those caused by their suppliers. This means that organisations may face legal consequences and penalties not only for their own actions but also for violations within their supply chains. The main aspects of the CSDDD are elaborated in Table 1.

Table 1. The main points of the CSDDD summarised.

DIRECTIVE (EU) 2024/1760 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on corporate sustainability due diligence and amending Directive (EU) 2019/1937 and Regulation (EU) 2023/2859* **Drawn from the Official Journal of the European Union** European Coalition for Corporate Justice (2024; European Commission (2024; European Parliament & Council of the European Union (2024)		
Section	Description	Article(s) Point(s)
Legal basis	The Directive has regard to the Treaty on the Functioning of the European Union, specifically Article 50(1), Article 50(2)(g), and Article 114.	-
Main objective	The Directive aims to ensure that organisations active in the internal market contribute to sustainable development and the sustainability transition of economies and societies through the identification, and where necessary, prioritisation, prevention and mitigation, bringing to an end, minimisation and remediation of actual or potential adverse human rights and environmental impacts connected with organisations' own operations, operations of their subsidiaries and of their business partners in the chains of activities of the organisations, and ensuring that those affected by a failure to respect this duty have access to justice and legal remedies.	1
Obligation	Covered organisations must establish and implement comprehensive due diligence processes to manage risks related to human rights and environmental impacts, which includes continuously monitoring, addressing, and mitigating these impacts throughout their operations and value chains, thereby ensuring accountability and transparency in their practices.	7-16
Environmental concerns	The directive aims to identify, prevent, mitigate, and account for negative impacts including environmental issues such as greenhouse gas emissions, pollution, biodiversity loss. It also includes respect of the rights to a clean and sustainable environment.	10, 12, 15, 22**
Social concerns	The directive aims to address the negative effects of human rights problems, including forced labour, child labour, inadequate health and safety at the workplace and the exploitation of workers.	10, 11, 12**

Liability	Organisations are liable for damages if they fail to comply with due diligence obligations. An organisation is considered liable if it caused or contributed to an adverse effect. If the adverse effect is due to the actions of a business partner, the organisation may still choose to provide voluntary remediation. The remediation includes financial or non-financial compensation for those affected, as well as compensation of costs made by public authorities for necessary remedial actions taken. Liability covers adverse human rights and environmental impacts that could have been prevented or mitigated and allows individuals and communities affected to claim compensation under the Directive.	29 (58)
Guidance	Organisations are guided by frameworks including the UN Guiding Principles Reporting Framework and UN Guiding Principles Interpretative Guide. The Commission may also issue guidance in consultation with Member States and stakeholders, the European Union Agency for Fundamental Rights, the European Environment Agency as well as international bodies having expertise in due diligence. Guidelines will, for instance, cover best practices for due diligence, sector-specific guidance, risk assessment, and stakeholder engagement.	18-21
Coordination of regulatory, investigative, and supervisory practices	Member States should designate one or more national supervisory authorities. Additionally, a European Network of Supervisory Authorities composed by the representatives of the supervisory national authorities will be set up.	23-26, 28
Penalties	Member States must establish effective, proportionate, and dissuasive penalties for violations of national laws aligned with the Directive, thereby considering factors including the nature and impact of the non-compliance, past violations, and any remedial actions taken. Penalties can include fines based on an organisations' net worldwide turnover. All penalty decisions will be publicly accessible for at least five years.	27
Supply chain integration	Due diligence extends to operations, subsidiaries, and value chains. Public authorities and private actors, in particular organisations, will be involved. To ensure appropriate measures to end or minimise actual adverse impacts, organisations should prioritise the engagement of business partners in their value chains over the termination of the business relationship, as terminations should be a last resort when all efforts to remediate the situation have been exhausted.	7, 8 (50, 57)
Scope	The directive applies to EU organisations with over 1,000 employees and a net worldwide turnover of more than EUR 450 million, as well as third-country organisations with significant turnover in the EU, while franchisors and licensors meeting specific financial thresholds are also included. Small and medium-sized enterprises (SMEs) do not have direct obligations but may be impacted as business partners of directly affected organisations. The SMEs may be required to collect and report information on adverse impacts. To protect SMEs, the Directive includes	2 (46, 54, 69, 71)

	provisions for support and safeguards against burdens passed on by directly affected organisations. In-scope organisations must adapt their purchasing practices and provide financial or non-financial support to SMEs under certain conditions. Support will also be made available to SMEs by the Member States.	
Entry into force	The directive has entered into force on the 13th of June, 2024. The CSDDD will be implemented in phases, requiring affected organisations to gradually comply with its requirements based on their size. All organisations are being expected to fully adhere by 2029.	36-38

*Note: This overview is a simplified version of the CSDDD and focuses on the main points and articles relevant for this research. The points were initially developed based on the Proposal for a Directive of the European Parliament and of the Council on Corporate Sustainability Due Diligence and amending Directive (EU) 2019/1937 European Commission (2022, pp. 27-68; European Parliament (2023). They have been updated after the official implementation of the CSDDD.
**Note: The details of the environmental and social requirements are described in the recitals of the final text.

Based on the scope outlined in Table 1, a framework has been developed that shows the main aspects of the CSDDD. The framework shows the various roles and links between the different actors operating within the scope of the CSDDD (Fig. 1).

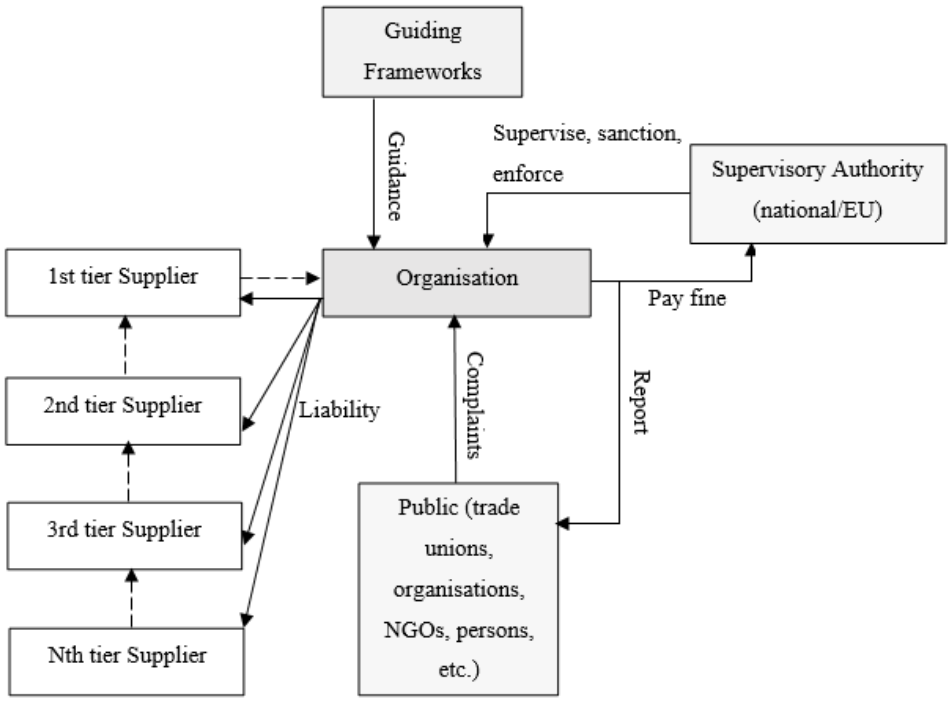


Figure 1. The CSDDD framework.

Beginning with the framework set out by the CSDDD, the focus shifts to the specific ESG obligations that emerge from corporate sustainability due diligence. By complying with the

obligations, organisations do not only improve their ethical reputation, but also contribute to a shift towards sustainable and socially responsible business practices.

2.1.3 The Corporate Sustainability Due Diligence Directive specific environmental and social obligations

The EUs CSDDD establishes a broad framework that includes social and environmental aspects, and requires organisations to align with internationally recognised objectives and prohibitions and promotes a global corporate responsibility approach.[22]

As part of the environmental aspect, organisations are required to prevent violations in connection with biological resources, trade in endangered species, governed by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), and the production and use of hazardous substances. This obligation also extends to the conventions on mercury, Persistent Organic Pollutants (POPs) and the protection of the ozone layer. Compliance with conventions and other regulations is important, including a focus on responsible waste management, particularly for the management of hazardous waste.

Furthermore, organisations need to ensure sustainable practices that include aspects such as the prevention of harmful soil degradation, water or air pollution and harmful emissions.

The social dimension of the CSDDD framework includes a broad range of responsibilities that ensure ethical business practices and respect for human rights. Compliance with labour and human rights includes ensuring the right to life, safety and freedom from torture or degrading treatment. Also, strict prohibitions on child labour and exploitation based on international standards are mandatory.

Furthermore, workers' rights and fair practices are crucial and include the right to freedom of association, freedom of assembly and collective bargaining. Organisations have to ensure fair wages, equitable working conditions, and protection against discrimination to promote a supportive and inclusive work environment. In recognition of the importance of living wages, organisations should ensure fair wages for all workers, thereby contributing to a decent standard of living. In addition, respect for territories and resources is of importance.

[22] See European Commission (2022, 2023); European Parliament (2023).

In summary, the CSDDD emphasises the need for due diligence, ethical practices, and alignment with regulatory standards to make an impact to sustainable and socially responsible business practices. More information about the environmental and social obligations is shown in Table 2.

Table 2. The environmental and social obligations of the CSDDD.

Social and environmental aspects of the CSDDD* **Based on (the Annex to) the DIRECTIVE (EU) 2024/1760 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 June 2024 on corporate sustainability due diligence and amending Directive (EU) 2019/1937 and Regulation (EU) 2023/2859** European Coalition for Corporate Justice (2024; European Parliament & Council of the European Union (2024)			
Aspect	Description	Obligation/prohibition	Conventions/treaties/ covenants
Environ-mental	Measures to avoid adverse impacts on biological diversity	Obligation to avoid or minimise adverse impacts on biological diversity.	Convention on Biological Diversity, Article 5 Cartagena Protocol, Nagoya Protocol
	Trade in endangered species	Prohibition on the trade of endangered species without a permit.	Convention on International Trade in Endangered Species (CITES), Articles 3, 4, and 5
	Mercury management	Prohibition on the manufacture, import, and export of mercury-added products and processes.	Minamata Convention on Mercury Articles 4, 5, and 11
	Chemical control	Prohibition on the import and export of hazardous chemicals and pesticides without consent.	Stockholm Convention on Persistent Organic Pollutants, Article 3(1)(a)(i) Regulation (EU) 2019/1021, Article 7 Rotterdam Convention on the Prior Informed Consent Procedure, Articles 10(1), 11(1)(b), 11(2)
	Ozone layer protection	Prohibition on the unlawful production and trade of substances depleting the ozone layer.	Montreal Protocol on Substances that Deplete the Ozone Layer, Article 4 Regulation (EC) No 1013/2006, Articles 34, 36
	Waste management	Actions to minimise harmful generation and mismanagement of waste.	Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, Article 4
	World natural heritage protection	Obligation to avoid or minimise adverse impacts on natural heritage sites.	Convention Concerning the Protection of the World Cultural and Natural Heritage, Article 5
	Wetlands protection	Obligation to avoid or minimise adverse impacts on designated wetlands.	Ramsar Convention on Wetlands, Article 4

	Marine pollution from ships	Prohibition on various forms of pollution from ships, including oil, chemicals, and garbage.	MARPOL (International Convention for the Prevention of Pollution from Ships) 73/78
	Marine pollution prevention	Obligation to prevent, reduce, and control marine pollution by dumping.	United Nations Convention on the Law of the Sea (UNCLOS), Article 210
	Soil conservation and prevention of land degradation	Measures to protect and enhance soil quality, preventing degradation of land through sustainable practices.	International Covenant on Civil and Political Rights (ICCPR), Article 6 International Covenant on Economic, Social and Cultural Rights, Articles 11 and 12
	Greenhouse gas emissions reduction	The obligation to achieve reductions in greenhouse gas emissions.	Paris Agreement, Regulation (EU) 2021/1119
	Air quality management	Initiatives to prevent and reduce air pollution.	International Covenant on Civil and Political Rights (ICCPR), Article 6 International Covenant on Economic, Social and Cultural Rights, Articles 11 and 12
	Forst protection and anti-deforestation	Efforts to prevent deforestation and promote sustainable forestry practices.	International Covenant on Civil and Political Rights (ICCPR), Article 6 International Covenant on Economic, Social and Cultural Rights, Articles 11 and 12
Social	Right to life	Protection against threats to life due to lack of proper instruction or control.	International Covenant on Civil and Political Rights (ICCPR), Article 6
	Prohibition of torture and inhumane treatment	Protection against torture and cruel, inhuman, or degrading treatment.	International Covenant on Civil and Political Rights (ICCPR), Article 7
	Right to liberty and security	Protection of personal liberty and security.	International Covenant on Civil and Political Rights (ICCPR), Article 9
	Privacy and reputation	Protection against arbitrary interference with privacy, family, home, or correspondence.	International Covenant on Civil and Political Rights (ICCPR), Article 17
	Freedom of thought, conscience, and religion	Protection of freedom of thought, conscience, and religion.	International Covenant on Civil and Political Rights (ICCPR), Article 18
	Just and favourable work conditions	Right to fair wages, safe working conditions, and reasonable work hours.	International Covenant on Economic, Social and Cultural Rights (ICESCR), Articles 7 and 11
	Access to basic necessities	Prohibition of restricting access to adequate housing, food, clothing, water, and sanitation for workers.	International Covenant on Economic, Social and Cultural Rights (ICESCR), Article 11

	Child rights and protections	Protection of children's health, education, and protection from exploitation and harmful work.	Convention on the Rights of the Child (CRC), Articles 24, 28, 27, 32, 34, and 35
	Child labour	Prohibition of employing children under the age of 15 or in hazardous conditions.	International Labour Organization (ILO) Minimum Age Convention (No. 138) and Worst Forms of Child Labour Convention (No. 182)
	Forced or compulsory labour	Prohibition of forced labour, including debt bondage and human trafficking.	International Labour Organization (ILO) Forced Labour Convention (No. 29) and Abolition of Forced Labour Convention (No. 105)
	Slavery and human trafficking	Prohibition of all forms of slavery and slave trade, including practices akin to slavery.	International Covenant on Civil and Political Rights (ICCPR), Article 8
	Freedom of association and collective bargaining	Rights to form or join trade unions and engage in collective bargaining.	International Labour Organization (ILO) Conventions No. 87 and No. 98
	Equal treatment in employment	Prohibition of discrimination in employment and remuneration based on gender, race, or other status.	International Labour Organization (ILO) Conventions No. 100 and No. 111, and ICESCR Article 7
	Protection against environmental degradation	Prohibition of activities causing significant environmental harm affecting human rights.	International Covenant on Civil and Political Rights (ICCPR), Article 6 and ICESCR Articles 11 and 12
	Right to land and resources	Protection of communities' rights to land and resources and against unlawful eviction.	International Covenant on Civil and Political Rights (ICCPR), Article 1 and 27, and ICESCR Articles 1, 2, and 11
Human rights and fundamental freedom instruments (Annex Part I(2)) The International Covenant on Civil and Political Rights; The International Covenant on Economic, Social and Cultural Rights; The Convention on the Rights of the Child; The International Labour Organization's core/fundamental conventions: Freedom of Association and Protection of the Right to Organise Convention, 1948 (No 87); Right to Organise and Collective Bargaining Convention, 1949 (No 98); Forced Labour Convention, 1930 (No 29) and its 2014 Protocol; Abolition of Forced Labour Convention, 1957 (No 105); Minimum Age Convention, 1973 (No 138); Worst Forms of Child Labour Convention, 1999 (No 182); Equal Remuneration Convention, 1951 (No 100); Discrimination (Employment and Occupation) Convention, 1958 (No 111)			

*Note: the overview is a simplified, and non-exhaustive version of the DIRECTIVE (EU) 2024/1760 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on corporate sustainability due diligence and amending Directive (EU) 2019/1937 and Regulation (EU) 2023/2859.

The focus on increased sustainability and compliance with ESG regulations, such as the obligations shown in Table 2, is assumed to have several advantages. For instance, it includes the promotion of internal integration within organisations and the expansion of external integration with suppliers and customers. This allows organisations to continuously learn from collaborations within supply chains, which can lead to improved efficiency and performance.[23] Furthermore, as proposed by Reuter et al. (2010, p. 58), continuous efforts towards sustainable development improve responsiveness, in other words, organisations can respond quicker and more effectively to emerging supplier issues and changing stakeholder expectations.

However, the complexity of global supply chains, in combination with developments such as new (ESG) regulations and obligations, results in an increasing number of (supply chain) uncertainties.

2.2 Uncertainties and risk management in Purchasing and Supply Management

2.2.1 Requirements lead to uncertainties and risks in Purchasing and Supply Management

The regulatory requirements and obligations can be expected to lead to uncertainties and related risks[24]. For instance, the ESG regulations will hold organisations accountable not only for their own sustainability practices, but also for the behaviour and practices of their nth-tier suppliers. Therefore, directives such as the CSDDD can only be achieved if there is a shared understanding of sustainability performance between the focal organisation and its suppliers.[25]

However, as supply chains are often long and complex, it can be challenging to establish transparency beyond the tier-1 supplier and even more challenging to drive a sustainability agenda upstream into the supply base.[26] Also Foerstl et al. (2018, p. 215) found that, despite the use of specific information processing mechanisms, it remains difficult to prevent sustainability misconduct in supply chains due to cost and complexity factors[27]. This sustainability-related uncertainty can be defined as the uncertainty faced by decision makers

[23] See Whitelock (2019), p. 930.
[24] See Felbermayr et al. (2021), p. 3.
[25] See Shafiq et al. (2017), p. 1400.
[26] See van Hoek et al. (2020), p. 6.
[27] Dai and Tang (2022), p. 7.

and procurement managers regarding sustainability practices in their upstream supply chain, particularly extending beyond the first-tier supplier level.[28]

Furthermore, as elaborated by Felbermayr et al. (2022, p. 47), a regular analysis of suppliers for human rights and environmental risks can be expected to result in an increase of costs. For instance, a subsequent reduction in the number of suppliers can be expected, especially impacting developing countries where compliance monitoring is challenging, possibly resulting in supplier concentration within those countries or supply chain relocation to the domestic market, on the condition that suitable suppliers are available[29]. This, in turn, could result in increased production costs, higher consumer prices, and reduced competitiveness, potentially ceding market share to strategic rivals such as China.[30] Furthermore, with an increasing dependence on remaining suppliers, the likelihood of supply bottlenecks might increase[31], which in turn could weaken the resilience of the European economy overall[32]. Additionally, it is plausible to expect that uncertainties related to imposed fines will arise[33], also because violations could initially remain undetected[34].

Although scholars have explored frameworks and metrics for successful ESG-related decision-making and value creation in organisations[35], coping with the uncertainties related to mandatory compliance with new regulations remains challenging, also due to a lack of standardised methods or levers. This integration of uncertainties into PSM draws attention to the interrelated risks.

2.2.2 Categorisation of risks in Purchasing and Supply Management

According to Schiele et al. (2021, p. 56), supply chain risk can be defined as "the chance of an undesired event associated with the inbound supply of goods and/or services which have a detrimental effect on the purchasing firm and prevent it from meeting customers' demands within anticipated cost and time"[36]. Various scholars discuss the concept of supply chain risk and its categorisation. One primary example is the categorisation pyramid created by

[28] See Foerstl et al. (2018), p. 204.
[29] See Felbermayr et al. (2021), p. 15.
[30] See Felbermayr et al. (2022), p. 47.
[31] See Felbermayr et al. (2021), p. 15; Felbermayr et al. (2022), p. 47.
[32] See Felbermayr et al. (2022), p. 47.
[33] See Shafiq et al. (2017), p. 1389.
[34] See Felbermayr et al. (2021), p. 14.
[35] See e.g. Whitelock (2019), pp. 925, 928.
[36] Hoffmann et al. (2013), p. 201.

Schiele et al. (2021, p. 56), who categorised supply chain risk into two primary domains: environmental risk and behavioural risk (Fig. 2).

Figure 2. The categorisation of supply risk (Schiele et al. (2021, p. 56)).

Environmental risk sources can be described as events within the supply chain environment that can lead to issues, such as acts of terrorism, labour strikes, or environmental disasters, impacting all organisations within the corresponding market.[37] Other scholars similarly refer to environmental risk as external, uncontrollable changes[38] or factors affecting the broader business context across industries[39].

Behavioural risks are sources of risks that are inherent to the characteristics of a buyer-supplier relationship and originate either from the supplier or within the relationship itself.[40] Behavioural risks can be further divided into three types of risks; (1) financial risks, referring to the potential change in a supplier's insolvency, or bankruptcy; (2) operational risks, which refer to a supplier's inability to meet the buyer's specified requirements; and (3) strategic risks, referring to a supplier's reluctance to comply with the buyer's requirements, despite having the capacity to do so.[41]

[37] Schiele et al. (2021), p. 56.
[38] See Rahman et al. (2023), p. 4.
[39] See Rao and Goldsby (2009), p. 107.
[40] See Schiele et al. (2021), p. 56.
[41] See Schiele et al. (2021), p. 56.

Even if regulatory risks initially seem to be linked to environmental risks given their broad impact on market participants[42], it is important to distinguish them as they are not part of natural disasters. Regulatory risks might therefore seem to be more closely related to operational risks, as these are, as elaborated before, about meeting specified requirements and may not apply to all organisations[43]. Some scholars refer to other risk areas. For instance, Wagner & Bode (2008, p. 311) researched regulatory, legal and bureaucratic risks in supply chains, that arise from uncertainties related to the enforcement and modification of laws and policies. These external factors can have a significant impact on supply chain design, operations, and performance, often leading to disruptions as administrative decisions or legal changes are difficult to predict.

However, it is important to note that in contexts such as the CSDDD, where predictability may be higher, the research by Wagner & Bode (2008, p. 311) remains relevant as it emphasises that engaging in more complex supply chains to meet environmental requirements can lead to higher supply chain costs. This is a notable risk factor, as higher complexity and higher costs can bring their own challenges for organisations.

Other scholars combine the two risks and write about geopolitical factors, that include governmental, natural, and social disruptions that bring uncertainty due to political events, natural occurrences, and social issues, which can have an overall impact on supply chain dynamics.[44]

Wiedenmann & Größler (2021, p. 661) write about specific risks, including compliance risks, such as the breach of laws and contracts, and the disregard of environmental and sustainability aspects that represent an important aspect of regulatory challenges. These risks are closely tied to the uncertainties related to the enforcement and change of laws and policies. This increasing complexity of global supply chains leads to an increasing need for risk management[45].

[42] See Schiele et al. (2021), p. 56.
[43] See Schiele et al. (2021), p. 56.
[44] See Ellis et al. (2011), p. 84.
[45] See Wiedenmann and Größler (2021), p. 650.

2.2.3 The risk management process can be categorised into risk identification, assessment, management, and monitoring

The performance of supply risk management can be described as "the extent to which the buying firm is able to recognise and monitor potential risks in due time to react, and in case of risk occurrence is able to minimise the impact this risk has on the buying firm" [46].

Various scholars have categorised the management of supply risk into several constructs or stages. For instance, Jüttner et al. (2003, p. 9) defined the following four basic constructs of supply risk management; (1) assessing the sources of supply chain risk, (2) defining the most relevant risk consequences, (3) tracking the risk drivers in the supply chain strategy and (4) mitigating risks. Similarly, Hallikas et al. (2004, p. 52); Hoffmann et al. (2013, p. 199) divided supply risk management into the following four stages; (1) risk identification, (2) risk assessment, (3) risk management and (4) risk monitoring, as shown in Figure 3.

Figure 3. The four stages of supply risk management (Hallikas et al. (2004, p. 52); Hoffmann et al. (2013, p. 199)).

Risk identification and assessment are generally regarded as the first stages in a risk management process.[47] The process of risk identification involves the recognition and understanding of potential uncertainties or sources of risks.[48] For instance, increasing the visibility of supply chains can be an important step towards the identification of possible risk sources.[49] Additionally, information sharing between buyers and suppliers, or initiatives to increase supply chain information transparency has a positive impact on operational performance, particularly in terms of cost, quality and delivery.[50] Similarly, Wiedenmann & Größler (2021, p. 665) emphasise the importance of considering the entire supply network, taking into account a diverse range of supply relationships and specialists from various areas, including compliance and information systems.

[46] Hoffmann et al. (2013), p. 201.
[47] See Jüttner et al. (2003), p. 9; Hoffmann et al. (2013), p. 199.
[48] See Hoffmann et al. (2013), p. 199.
[49] See Chowdhury et al. (2022), p. 1.
[50] See Difrancesco et al. (2022), p. 620.

Risk assessment involves the evaluation of the identified risk factors based on their probability and consequences and prioritising them.[51] The management of risks includes strategies such as risk taking, transfer, elimination, minimisation, and detailed analysis to address and manage potential risks.[52] Risk management can take either a pro- or reactive approach, with regulatory disruptions most often being addressed reactively due to their unpredictable and exogenic nature.[53]

Risk monitoring can be defined as the use of indicators to regularly evaluate the likelihood of, and possible changes within the occurrence of risks.[54] Shafiq et al. (2017, p. 1400) refer to behavioural monitoring approaches, such as monitoring suppliers' environmental and social practices, which appear to be a suitable method to enhance an organisations' sustainability performance.[55]

Identifying, assessing, managing, and monitoring various risks are core concepts that can lead to an increased supply chain resilience, as well as reduced vulnerability, thereby ensuring efficiency and sustainability of supply chains. However, it should be noted that mitigating disruptions through resilience can result in an increase of costs, and resolving every possible threat would be impossible as it would require excessive investment.[56]

Resilient supply chains strategically implement measures, such as the diversification of suppliers, guaranteed long-term contracts, rapidly switching sources and rerouting supplies to minimise disruption, decrease performance loss and shorten recovery times.[57]

Conclusively, managing supply risks resulting from the implementation of new regulations, such as the CSDDD, is a great challenge. The complexity of compliance emphasises a need for a more thorough approach beyond the traditional management of risks. The research by Hoffmann et al. (2013, p. 207) emphasises that continuous improvement in cross-functional risk management combined with a focus on maturity positively influences risk identification, assessment and mitigation, thereby emphasising the need for an assessment framework for supply chain risk management.

[51] See Hallikas et al. (2004), p. 53.
[52] See Hallikas et al. (2004), p. 54.
[53] See Buchholz et al. (2022), p. 703.
[54] See Hallikas et al. (2004), p. 54; Hoffmann et al. (2013), p. 202.
[55] See Shafiq et al. (2017), p. 1400.
[56] See Buchholz et al. (2022), p. 704.
[57] See Buchholz et al. (2022), p. 704.

It is important to recognise that emerging technologies play an important role in improving the risk management process. Consequently, the focus shifts towards examining the development of digitalisation within the field of PSM.

2.3 The digitalisation in the field of Purchasing and Supply Management started in the late 1980s

2.3.1 The historical evolution of digitalisation: From steam power and mechanisation to artificial intelligence

The integration of technology in the field of PSM is undergoing a great development, which is characterised by the introduction of Industry 4.0. Due to changing customer demands, flexibility, innovation, and the ability to adapt to change are increasingly important.[58] The focus on flexibility and innovation has driven the digitalisation of industries and led to rapid developments in industries and industrial production.[59]

At an international level, various countries and groups of countries have introduced strategic technology concepts. Examples include the New Industrial French in France, the Advanced Manufacturing Partnership Project in the United States, and the Made in China 2025 in China.[60] These initiatives share a common objective: they promote a modern industrial framework that includes a range of current and future technological developments.[61]

One of the best known and widely used term is the 2011 developed German Industry 4.0 or Fourth Industrial Revolution[62], which "represents the next step on the evolution of traditional factories towards actual smart factories, which are designed to be more efficient in terms of resource management and to be highly flexible to adapt to ever-changing production requirements"[63].

The industrial revolution, which has stretched over centuries, has caused the industrial landscape to undergo four different phases that have shaped economies and societies.[64] The first revolution began in the late eighteenth century with steam power and mechanisation, which laid the foundation for the manufacturing industry. The discovery of electric power

[58] Fusko et al. (2019), p. 1051.
[59] See Fernández-Caramés and Fraga-Lamas (2019), p. 45201; Fusko et al. (2019), p. 1051.
[60] See Fernández-Caramés and Fraga-Lamas (2019), p. 45201; Xu et al. (2021), p. 530; Coelho et al. (2023), p. 1138.
[61] See Coelho et al. (2023), p. 1138.
[62] See Coelho et al. (2023), p. 1138.
[63] Fernández-Caramés and Fraga-Lamas (2019), p. 45201.
[64] See Koh et al. (2019), p. 818; Yousif et al. (2022), p. 634.

and assembly lines in the twentieth century marked the second revolution, which increased productivity and production.[65]

The third revolution introduced a fundamental factor: computerisation. Computer technologies spread to all industrial sectors and redefined processes and procedures.[66] This era introduced progressive changes that fundamentally reshaped industries.[67]

The current century introduced the fourth industrial age, with intellect and artificial intelligence driving the revolution.[68] Industry 4.0 builds on the developments of Industry 3.0, but is characterised by its emphasis on automation, efficiency, agility, and sustainability.[69] Figure 4 shows the four stages of industrial revolution.

Industrial Revolution		Period	Technologies
	IR 4.0	2011 – Present	Big Data, Cyber Physical System, Additive Manufacture, Cloud Computing, Virtual and Augmented Reality, RFID, Drones, etc.
	IR 3.0	Start of the 1950s	Automation, Computers, and electronics
	IR 2.0	Start of 20th Century 1870 – 1914	Mass production, Assembly line, Electrical energy
	IR 1.0	End of 18th Century 1760 ~ 1830	Mechanization, Steam power, Weaving loom

Figure 4. The four stages of industrial revolution (Yousif et al. (2022, p. 634)).

2.3.2 Exploring Industry 4.0: Features, business applications and challenges

Industry 4.0 features

Industry 4.0 knows various interpretations and definitions. However, most definitions are consistent with the following design principles as described by Vogel-Heuser & Hess (2016, p. 411). A central principle is the implementation of intelligent, self-organising Cyber-Physical Production Systems (CPPS). Interoperability is important, which supports

[65] See Koh et al. (2019), p. 818; Yousif et al. (2022), p. 634.
[66] See Koh et al. (2019), p. 818.
[67] See Yousif et al. (2022), p. 634.
[68] See Yousif et al. (2022), p. 634.
[69] See Laffi and Boschma (2022), p. 6.

connections and communication between humans, Cyber-Physical Systems (CPS), and CPPS. I4.0 focuses on seamless connectivity and communication and relies on cross-disciplinary modularity that enables flexible adaptation to changing requirements. The provision of big data algorithms in real time enables informed decision-making, while the aim is to continuously improve Overall Equipment Effectiveness (OEE) through ongoing optimisation. At the centre of the concept is data integration across the entire product lifecycle, which is achieved through model-driven modular engineering processes. Secure communication promotes industrial partnerships, and the focus on data access and secure storage extends to both Cloud and Intranet environments.[70]

Building on the I4.0 foundation provided by the Reference Architecture Model included in Appendix I, the fundamental design principles emphasise the importance of networked systems, intelligent manufacturing processes and advanced technologies. These principles contribute to a consistent understanding of the technologies of I4.0.

Industry 4.0: Technological advancements and business opportunities
Several Industry 4.0 technologies have gained significant recognition over the years. The selection of the advanced technologies explained underneath is based on their dominant role in recent academic literature (e.g. Fernández-Caramés & Fraga-Lamas (2018); Balasubramanian et al. (2021); Nimmy et al. (2022)), and industry reports.

For instance, Boston Consulting Group researched the impact of I4.0 on future productivity and growth in manufacturing industries and discussed nine key enabling technologies that form the foundation of I4.0, which change traditional manufacturing relationships from "Isolated, optimised cells to fully integrated data and product flows across borders"[71]. These key technologies include big data and analytics, autonomous robots, simulation, horizontal and vertical system integration, Industrial Internet of Things (I-IoT), cybersecurity, cloud computing, Additive Manufacturing (AM), and Augmented Reality (AR).[72] Fernández-Caramés & Fraga-Lamas (2018, p. 25941) explored smart factory technologies and discussed additional advancements such as Automated Guided Vehicles (AGV), edge computing, simulation software, Virtual Reality (VR), and CPS. The related fields of these

[70] See Vogel-Heuser and Hess (2016), p. 411.
[71] Rüßmann (2015), p. 4.
[72] See Rüßmann (2015), pp. 5-7.

technologies include, for instance, smart objects and appliances, blockchain technologies,[73] as well as AI and its subgroup Machine Learning (ML)[74].[75]

The technologies play a crucial role in today's increasingly competitive industry landscape. As businesses become more digital and adopt various I4.0 technologies, they enable many opportunities for them to improve their operations. The concept of 'smart' competing emerges, demanding higher quality standards for products and services and emphasising the importance of aspects such as speed, precision, availability, uniqueness, convenience, and flexibility.[76]

Industry 4.0 challenges

Besides numerous opportunities, Industry 4.0 comes with several limitations and challenges. These limitations include various aspects, such as insufficient funds for digital infrastructure development, high investment requirements, challenges in data management and quality issues associated with the handling of big data, the absence of well-defined digital strategies, low technology maturity levels, uncertainty regarding the economic benefits, cybersecurity challenges, resistance among the workforce to adopting new technologies, and insufficient skills.[77]

Furthermore, the implementation of new digital (I4.0) machines or systems directly impacts the workforce,[78] particularly displacing workers in low-skilled positions that could contribute to increased unemployment.[79] Frey and Osborne (2013) emphasise a negative relationship between wages, education, and the likelihood of automation. This suggests a change in demand for skilled labour due to advancing technology. Consequently, there could be a potential reallocation of tasks, which could push low-skilled workers toward positions that require creative and social intelligence. This shift emphasises the need for these workers to acquire new skills to remain successful in the changing job landscape.[80] Similarly, Kipper et al. (2020, p. 1615) contributed to the discussion and state that technological innovations require workers to be flexible and adaptable to keep pace with the rapid changes. This requires a need for focused training efforts to educate highly skilled professionals who need

[73] See Fernández-Caramés and Fraga-Lamas (2018), p. 25941.
[74] See Nimmy et al. (2022), p. 9.
[75] See Balasubramanian et al. (2021), p. 6.
[76] See Grabowska et al. (2020), p. 34.
[77] See Attiany et al. (2023), p. 300.
[78] See Attiany et al. (2023), p. 300.
[79] See Hirsch-Kreinsen (2016), p. 6; Furstenau et al. (2020), p. 140090.
[80] See Frey and Osborne (2013), p. 271.

to manage large amounts of data, perform multiple tasks simultaneously, solve complex problems, drive innovative business change, and collaborate effectively with robots while mastering advanced human-machine interaction technologies.[81]

Beyond these workforce challenges, the integration of I4.0 technologies into processes and practices faces hurdles. While processes can be combined and automated, enabling higher levels of transaction automation, efficiency and effectiveness[82], it is important to recognise that many technologies, such as blockchain[83] and Robotic Process Automation (RPA)[84] are still in the phase of development, and the adoption of new technologies can be challenging.[85] For instance, many technologies are mainly adopted by large, mature corporations, given that integrating new technologies still demands significant investment and resources.[86] The situation becomes increasingly complicated as suppliers and manufacturers need to be open to new technologies.[87] Bodendorf et al. (2022, p. 801) and Herold et al. (2022, p. 435) state that effective collaboration with external parties is key to successfully engaging with innovative ecosystems and achieving knowledge exchange, thereby speeding up technology acceptance. Furthermore, a comprehensive infrastructure (including skilled, motivated employees and reliable internet connectivity) is required.[88] Fostering trust, perceiving opportunities versus risks, and strategically defining core competencies and visions are therefore key to addressing the challenges and opportunities of I4.0 technologies.[89]

2.3.3 Technologies in Purchasing and Supply Management include Artificial Intelligence and blockchain technology

Technological development and integration in Purchasing and Supply Management

Advances in technology have also significantly changed the field of PSM over decades. For instance, traditional software systems, such as Enterprise Resource Planning (ERP) systems play a key role since the late 1980s[90]. E-procurement includes the management of supply chains for the procurement of supplies based on internet and information technologies, as well as electronic marketplaces.[91]

[81] See Furstenau et al. (2020), p. 140090; Kipper et al. (2020), p. 1615.
[82] See Rejeb et al. (2018), p. 84.
[83] See Kopyto et al. (2020), p. 9.
[84] See Flechsig et al. (2022), p. 1.
[85] See Rejeb et al. (2018), pp. 83-84.
[86] See Fudurich et al. (2021), p. 6.
[87] See Rejeb et al. (2018), pp. 84-85.
[88] See Rejeb et al. (2018), pp. 84-85.
[89] See Bienhaus and Haddud (2018), pp. 979-980; Attiany et al. (2023), p. 300.
[90] See Puschmann and Alt (2005), p. 122.
[91] See Dolmetsch et al. (2001), p. 194; Puschmann and Alt (2005), p. 122.

In the age of Industry 4.0, several scholars research how the advancements of digitalisation are currently shaping the field of PSM, while also considering their implications for future developments. For instance, Colombo et al. (2023, p. 11) researched socio-technical impacts of digitalisation in the field of PSM. Their research emphasises how automation increases efficiency by replacing human tasks and enabling greater autonomy in decision-making, particularly at a tactical and operational level. On the other hand, augmentation, enabled by automation and data aggregation, expands the strategic responsibilities of purchasing professionals and eventually increases the effectiveness of the overall purchasing department.[92]

The benefits of digitalisation in the field of PSM include, for instance, reduced administrative effort, early cross-functional PSM involvement in design processes, increased productivity due to reduced supplier lead times, improved supplier responsiveness, reduced risk of supply shortages, increased agility and traceability, competitive pricing and the promotion of collaborative relationships.[93] However, the main challenges relate to the quality of master data, security concerns, the willingness of suppliers to collaborate digitally and the lack of clearly defined processes, roles and responsibilities.[94] Delke et al. (2023, p. 13) predict six future roles in PSM, including Data Analyst, Legislation Specialist and Process Automation Manager, that are expected to become increasingly important to adapt to the complex technological integration.

Building on technological advances in PSM, it is necessary to analyse the role of technologies such as AI and blockchain, that offer unique solutions and opportunities within the field of PSM.

Artificial Intelligence

One example of an Industry 4.0 technology often used in the field of PSM is Artificial Intelligence, which can be referred to as the ability of computers to "learn and comprehend new concepts, learn from experience ("on-their-own"), perform reasoning, draw conclusions, impute meaning, and interpret symbols in context"[95]. Thus, AI has the potential to support complex decision-making processes by rapidly analysing large datasets (big data), almost in real-time, thereby highlighting the most suitable options.[96] This can, especially in

[92] See Colombo et al. (2023), p. 11.
[93] See Srai and Lorentz (2019), p. 86.
[94] See Srai and Lorentz (2019), p. 86.
[95] Min (2010), p. 14.
[96] See Bienhaus and Haddud (2018), p. 978; Allal-Chérif et al. (2021), p. 75.

dynamic situations as supply chain disruptions, be crucial. As stated by S. Gupta et al. (2021, p. 7), implementing AI-based data collection, processing and self-training capabilities and robust information systems not only mitigates the impact of supply chain disruptions, but also ensures optimised transport networks, geographically appropriate supply chains and cyber security.[97] Additionally, Artificial Intelligence can be combined with techniques such as Multi-Criteria Decision Making (MCDM) to support the supplier selection process, which, as stated by Resende et al. (2021, p. 493), is "one of the most important decisions in the supply chain management context". Besides the mentioned applications, AI can provide support for demand planning and forecasting[98], process automation[99], as well as to contribute to business-to-business negotiations[100]. Furthermore, AI can provide a higher level of flexibility and automation, enabling organisations to quickly adapt to the changing environment and improve the performance of supply chains by increasing resilience and reducing the risk of disruption.[101]

Blockchain technology

A blockchain can be defined as follows; "A blockchain is a distributed database, which is shared among and agreed upon a peer-to-peer network. It consists of a linked sequence of blocks, holding timestamped transactions that are secured by public-key cryptography and verified by the network community. Once an element is appended to the blockchain, it can not be altered, turning a blockchain into an immutable record of past activity"[102]. This description already emphasises the potential importance of blockchain in the field of PSM. In particular, it improves supply chain transparency[103], which is especially relevant in respect to the shift towards the globalisation of value-creating processes within supply chains[104], to optimise supplier relations and to be able to respond to the emergence of risks.[105] Furthermore, as blockchain technology maintains information within immutable blocks[106],

[97] See S. Gupta et al. (2021), p. 7.
[98] See Atwani et al. (2022), p. 4.
[99] See Allal-Chérif et al. (2021), p. 75.
[100] See Min (2010), p. 34.
[101] See Modgil et al. (2022), p. 1260.
[102] Seebacher and Schüritz (2017), p. 14.
[103] See Francisco and Swanson (2018), p. 3; Kouhizadeh and Sarkis (2018), p. 3; Shakhbulatov et al. (2020), p. 232; Kalaiarasan et al. (2022), p. 4.
[104] See Kappel et al. (2020), p. 796.
[105] See Kappel et al. (2020), p. 795.
[106] See Seebacher and Schüritz (2017), p. 14.

its utilisation in combination with cryptographic mechanisms ensures security and reliance of data.[107]

Additionally, blockchain technology can serve as foundation for smart contracts.[108] As elaborated by Kouhizadeh & Sarkis (2018, p. 4), smart contracts are computer codes that contain contract terms and operating policies created for automatic execution. These contracts evaluate predetermined conditions, which include commonly accepted rules and associated consequences, and trigger actions aligned with those conditions. An example of smart contracts is the automatic processing of payments when certain criteria are met.[109]

The Internet of Things

Also the Internet of Things (IoT) is part of the core components in the field of PSM, as it enables the automation of operational tasks.[110] Part of the IoT are Radio-Frequency Identification (RFID), sensors, networks, and cloud computing.[111] Although blockchain technology became the dominant key technology for supply chain visibility[112], also RFID can contribute to achieve this objective.[113] It serves as a tool for object identification and labelling, thereby improving transparency in product development throughout the supply chain and enabling tracking of produced and delivered inventory.[114] Moreover, RFID can help to reduce administrative tasks, improve productivity, decrease labour expenses, and enhance the precision of inventory forecasting.[115]

Machine-to-machine communication and cyber-physical systems

Machine-to-machine communication and cyber-physical systems are important parts in the field of I4.0-driven procurement, derived from I-IoT[116]. Schiele (2016, pp. 16-17) described the following two different scenarios regarding machine-to-machine communications within cyber-physical systems: The first scenario involves tightly coupled systems characterised by machine-to-machine communication within defined processes of established customer-supplier relationships. For example, self-replenishing containers that independently order and receive supplies demonstrate the cyber-physical aspect with automatic demand

[107] See Kouhizadeh and Sarkis (2018), p. 3.
[108] See Schütte et al. (2017), p. 19; Kouhizadeh and Sarkis (2018), p. 4; Shakhbulatov et al. (2020), p. 234.
[109] See Kouhizadeh and Sarkis (2018), p. 4.
[110] See Bienhaus and Haddud (2018), p. 974.
[111] See Haddud et al. (2016), p. 227.
[112] See Kalaiarasan et al. (2022), p. 4.
[113] See Osmonbekov and Johnston (2018), p. 23.
[114] See Oghazi et al. (2018), pp. 175-177.
[115] See Oghazi et al. (2018), pp. 175-176.
[116] See Xu et al. (2018), p. 78241.

generation and order placement. The second scenario involves loosely coupled systems that utilise electronic marketplaces, seeking unselected suppliers and variable prices through automatic cyber-negotiations that can systematically review a large number of options.[117]

Cyber-negotiation is a distinctive aspect of I4.0 technologies in the field of PSM. It involves predefined preference parameters and an iterative algorithm that compares and integrates these parameters. This process then negotiates with suppliers based on a predefined negotiation strategy with the aim of achieving an optimal outcome.[118]

Supporting and niche Industry 4.0 technologies

Besides the technologies mentioned before, other Industry 4.0 technologies in the field of PSM are present that are either playing a specialised role, or support capabilities of other core technologies. One example is Digital Twins (DTs). DTs, which are virtual representations of physical entities such as supply chains, include a bi-directional data flow between virtual and digital representations.[119] In the context of supply chains, DTs have four main purposes, as elaborated by van der Valk et al. (2022, p. 160). Firstly, they increase visibility and monitoring by making processes and data from physical assets transparent and visual, for instance with IoT sensors.[120] Secondly, DTs support optimisation by analysing real-time data, refining processes, and improving overall flow, resulting in better operational efficiency. Thirdly, DTs use data, algorithms, and past experiences to predict supply chain behaviour, providing forecasts that support decision-making. Lastly, DTs enable simulation by creating virtual models to allow for experimentation and scenario analysis.[121]

Furthermore, technologies such as collaborative robots (cobots), RPA, AM and the use of 5G play an important role in the field of PSM. While cobots help to optimise various functions within the supply chain, such as systematic inventory management, inventory tracking, efficient order processing and product return processes, RPA automates transaction and data management tasks, leading to increased operational efficiency and a reduction in workload. Additionally, RPA promotes digital maturity, standardisation of IT systems and a shift towards more strategic procurement functions, which can lead to an increased overall effectiveness.[122]

[117] See Schiele (2016), pp. 16-17.
[118] See Schiele (2016), p. 17.
[119] See van der Valk et al. (2022), p. 160.
[120] See Maddikunta et al. (2022), p. 7.
[121] See van der Valk et al. (2022), p. 160.
[122] See Flechsig et al. (2022), p. 14.

AM is an innovative digital technology that uses digital design files in abstract form that can be converted into a tangible object with a 3D printer.[123] 5G networks can improve connectivity and optimise communication between different parts of the supply chain.[124]

All the above technologies play an important role in the field of PSM. Not only do they contribute to operational efficiency, they can also play an important role in improving sustainability within the supply chain. As the field of PSM and the regulatory environment keep changing, the integration of advanced technologies can improve ESG risk management, thereby ensuring a more sustainable and responsible approach to PSM operations.

2.4 Technologies and ESG risk management: Improving transparency and sustainability

In the field of PSM, various technologies are required for effective management of ESG risks. Table 3 categorises these technologies systematically into the four key stages of risk management - risk identification, risk assessment, risk management and risk monitoring – following the classification as proposed by Hallikas et al. (2004, p. 52) and Hoffmann et al. (2013, p. 199).

[123] See Chan et al. (2018), p. 156.
[124] See Maddikunta et al. (2022), pp. 6, 11.

Table 3. Technology solutions for ESG Risk Management in the field of PSM.

Technological solutions for ESG Risk Management				
Technology	Risk management stage(s)	Contribution to risk management	Explanation	Source
Artificial Intelligence	Identification, Management	Supports digitalisation, promotes climate goals and improves resilience and decision-making. It is crucial for ESG risk management, monitoring trends and implementing solutions to reduce greenhouse gas emissions.	AI helps to recognise positive ESG factors, enabling the identification of organisations with high social and environmental value. It improves resilience, accountability, and decision-making. AI is crucial for ESG risk management, supporting climate targets, monitoring trends, and implementing solutions to reduce greenhouse gas emissions.	Płońska & Kądzielawski (2023, p. 531)
*Artificial Neural Networks (ANNs)**	Assessment	Models risk dependency graphs for accurate risk propagation, optimises response strategies.	ANNs can be used for modelling risk dependency graphs, thereby providing a broad understanding of consequences beyond financial loss, including environmental impact and psychological measures.	Baryannis, Dani, et al. (2019, p. 995)
*Bayesian Networks (BNs)/ Bayesian Network Modelling**	Assessment, Monitoring	Supports risk management by modelling relationships, offering insights beyond financial implications, encompassing environmental impact, network characteristics, and psychological measures. Developed measures support the improvement of supply chain resilience through informed mitigation and contingency planning.	BNs are used for modelling risk dependency graphs for accurate risk propagation, optimises response strategies, providing an understanding of consequences beyond financial losses, including environmental impact, network characteristics, and psychological measures. BNs can help to improve supply chain resilience by providing information for mitigation and contingency plans. BNs can also enable the development of probability distributions through measurable key risk indicators with the use of historical data. These distributions can be used in supply chain risk dashboards. BNs also enable the development of probability distributions and support continuous risk monitoring.	Garvey et al. (2015, p. 626) Baryannis, Validi, et al. (2019, p. 995) Kumar Sharma & Sharma (2015, p. 65) Calatayud (2017, pp. 31, 32)
*Machine Learning**	Identification, Assessment, Management	Can be used for risk assessment as these are capable to assess risks quickly and objectively. Improves precision in ESG risk identification, enables effective risk management.	ML and analysis of extensive datasets improve the identification of ESG risks, help to recognise positive factors, and identify organisations with high social and environmental value.	Płońska & Kądzielawski (2023, p. 533) Yang et al. (2023, p. 8)

*Note: These technologies are sub-technologies of Artificial Intelligence.

Technology	Risk management stage(s)	Contribution to risk management	Explanation	Source
Blockchain technology	Identification, Management, Monitoring	Improves transparency in supply chains, supports monitoring of environmental, social, and economic performance, enables verification and standardisation of certifications.	Blockchain allows stakeholders to access and validate information on carbon emissions, waste management, and fair-trade practices, leading to greater accountability and informed decisions. Sustainability and circular economy certifications can be verified and standardised through blockchain, thereby enabling proactive risk management in the supply chain. Blockchain technology can have a significant impact on the accuracy, reliability, incorruptibility, and timeliness of processes and transactions within the supply chain, which makes it an attractive option to improve resilience, accountability, and decision-making in risk management.	Kopyto et al. (2020, p. 9) Sanders et al. (2019, p. 233) Qian et al. (2023, pp. 13-14) Asif et al. (2023, p. 6) Park & Li (2021, p. 15) Chowdhury et al. (2022, p. 1)
Radio Frequency Identification	Identification, Assessment	Enhances supply chain transparency, providing valuable insights into ESG practices.	RFID contributes to improving transparency in the supply chain, ensuring organisations fulfil sustainability requirements.	Oghazi et al. (2018, p. 176)
Digital Twins/ Digital Twin Models	Identification, Assessment	Contribute to both risk assessment and identification, improving transparency in the supply chain and ensuring organisations fulfil sustainability requirements.	DTs contribute to improving transparency in the supply chain, ensuring organisations fulfil sustainability requirements. DT models can visualise the changes of supply chain risks over time, as well as function as a tool for stress testing supply chains, thereby providing insights into the impact of risk propagation.	Ivanov & Dolgui (2022, p. 483)
Robotic Process Automation	Monitoring	Promising for use in PSM, can analyse spendings and generate supplier risk maps.	RPA through bots analysing spendings and generating supplier risk maps can support the process of risk monitoring.	Flechsig et al. (2022, p. 1)
Enterprise Resource Planning	Assessment, Management	Can improve visibility and reduce risks.	Enhanced ERP positively affects supplier integration, internal integration, and green supply chain management. ERP can reduce risks of supply and improve visibility within organisations.	Koh et al. (2006, p. 461) Tarigan et al. (2021, p. 17)

Increased transparency in supply chains makes it easier to monitor the environmental, social, and economic performance of suppliers, which in turn improves the identification and management of risks.[125] One possible way to achieve transparency is through technologies like blockchain[126], as elaborated in section 2.3.3. As noted by Qian et al. (2023, p. 1),"Companies who recognise the blockchain's potential can improve corporate governance, environmental impact, and social good by increasing transparency, traceability, and accountability".

Kalaiarasan et al. (2022, p. 8) developed a supply chain visibility framework, that shows the antecedents, drivers, barriers and effects of achieving visibility in complex supply chains. In particular, the barriers and challenges of the model highlight that, among other factors, poor data quality, supply chain complexity and a lack of skills and knowledge are key barriers to supply chain visibility. These challenges can be mitigated through the use of the antecedents of the model, which include blockchain, which promotes data sharing as well as tracking and tracing in supply chains.[127]

However, concerns about accountability arise as blockchain can secure existing data, but not guarantee the authenticity of inputs. Addressing this challenge for sustainability involves securely converting physical or tangible evidence (including working conditions, toxic material use) into digital data, which experts currently identify as a bottleneck.[128]

Therefore, recognising the central role of active trust management in the integration of blockchain into supply chain management emphasises the acknowledgement that technological change involves more than just technical aspects.[129]

When investigating future scenarios, Kopyto et al. (2020, p. 9) researched possible application scenarios for the year 2035. Based on their research, it can be expected that future compliance with sustainability standards will be based on traditional reporting methods alongside selective blockchain-based support.[130]

Besides blockchain technology, the transparency of supply chains can be improved with various other technologies. As elaborated in section 2.3.3, RFID and DTs can provide

[125] See Sanders et al. (2019), p. 233.
[126] See Srai and Lorentz (2019), p. 80; Chowdhury et al. (2022), p. 1.
[127] See Kalaiarasan et al. (2022), p. 4.
[128] See Kopyto et al. (2020), p. 9.
[129] See Kopyto et al. (2020), p. 11.
[130] See Kopyto et al. (2020), p. 9.

valuable insights into ESG practices. In contrast, organisations with limited supply chain visibility are unlikely to fulfil sustainability requirements.[131]

In addition, various other technologies play a central role in addressing ESG related issues at all stages of risk management. For instance, AI is becoming a key player contributing to risk identification by increasing accuracy in identifying ESG risks and recognising positive ESG factors[132]. The application of ML and the analysis of extensive datasets improve the precision of ESG risk identification and enable more effective risk management.[133] Furthermore, as Płońska & Kądzielawski (2023, p. 531) emphasise, AI is proving to be essential for digitalising economies, supporting climate targets and implementing solutions to reduce greenhouse gas emissions. These technologies, in combination with RFID and DTs that provide valuable insights and transparency into ESG practices[134], can contribute to an inclusive framework for proactive risk management in PSM.

However, relying on a single method to address sustainability challenges within supply chains could oversimplify complex situations. Therefore, a broad framework can be required that includes several methods such as case studies, data mining, visualisation, analytics, empiricism, and computation to address various aspects of those challenges.[135] Moreover, not all technologies can be categorised easily into the various risk stages. For instance, Baryannis, Validi, et al. (2019, p. 2196) emphasise the different applicability of multiple AI techniques in the supply chain risk management phases, with mathematical programming showing strengths in risk avoidance but lacking in automated decision making, while ML techniques offer such capabilities but struggle in complex supply chain modelling. Therefore, exploring hybrid frameworks that combine, for instance, mathematical modelling with predictive and learning-based AI techniques has potential for an effective proactive and predictive risk management in supply chains.[136]

[131] See Busse et al. (2017), p. 33; Suh and Lee (2018), p. 17.
[132] See Płońska and Kądzielawski (2023), p. 531.
[133] See Płońska and Kądzielawski (2023), p. 531.
[134] See Oghazi et al. (2018), p. 176; Ivanov and Dolgui (2022), p. 483.
[135] See Sanders et al. (2019), p. 237.
[136] See Baryannis, Validi, et al. (2019), p. 2196; Nimmy et al. (2022), p. 14.

Figure 5 shows all relevant factors and their interaction for this research, considering ESG regulations, resulting supply risks, as well as the risk management approach and the role of technologies.

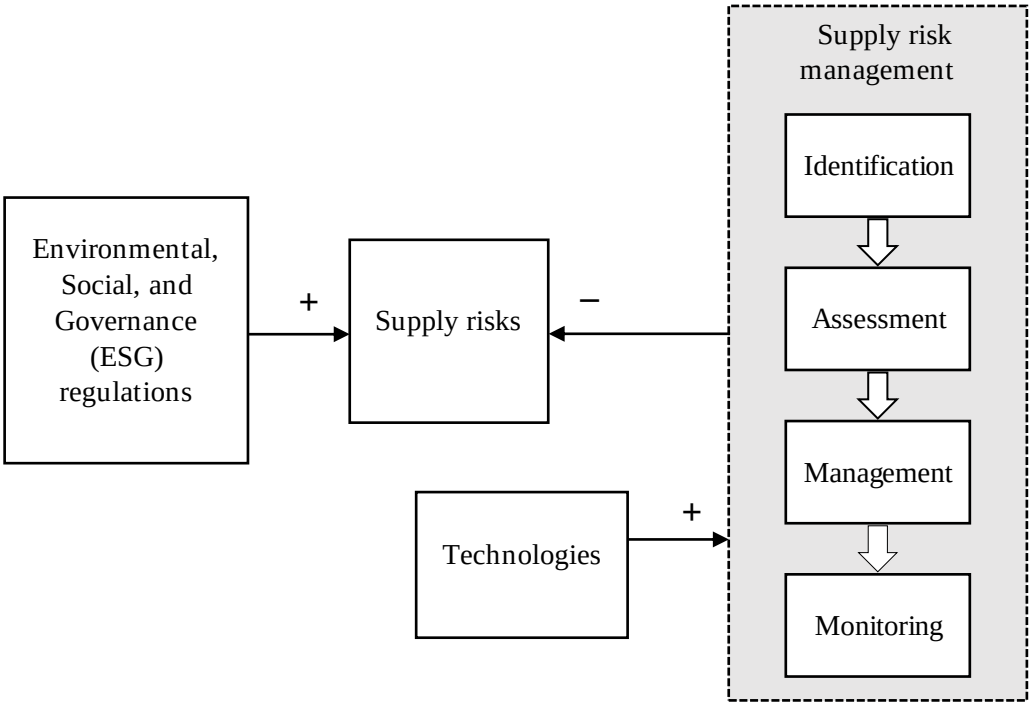


Figure 5. The theoretical framework, supply risk management model based on Hallikas et al. (2004, p. 52); Hoffmann et al. (2013, p. 199).

3. METHODOLOGY: CONDUCTING INTERVIEWS AND WEB-BASED RESEARCH TO ASSESS TECHNOLOGY IMPLICATIONS

3.1 Method justification and overall execution based on research process model

Qualitative research has been conducted for this research as the main aim of this research is to explore the natural contexts of research participants to understand their perceptions, practices, and the meanings they attach to them.[137] Specifically, exploratory research has been conducted. As described by Saunders et al. (2019, p. 187), exploratory research includes preliminary research methods such as literature reviews, expert panels, individual interviews or focus group interviews. Exploratory research is flexible and adaptable to new data, thereby allowing researchers to adjust their direction accordingly. Given the exploratory nature of interviews, it is likely that they are not strictly structured and instead rely on the quality of participants' contributions to guide the following phases of the research.[138]

In this research, expert interviews have been conducted to gain deeper insight into the perceptions of technology solution providers and buyers regarding the use of technologies and the management of ESG risks in the field of PSM.

The research has been conducted in multiple steps, based on the research process model developed by Saunders et al. (2019, p. 12). As starting point, the research topic, the main problem, and objective of the research have been defined. The literature review was then used to identify existing technological solutions for risk management in PSM, with a specific emphasis on ESG considerations and detailed requirements outlined in the CSDDD. The second step involved the development of the research design, followed by the development of interview protocols for technology providers and PSM experts/buyers, and conducting the interviews. Additionally, web-based research has been conducted to verify and to expand the dataset. As last step, all data has been analysed and synthesised. The research methodology is illustrated in Figure 6.

[137] See Moser and Korstjens (2017), p. 272.
[138] See Saunders et al. (2019), p. 187.

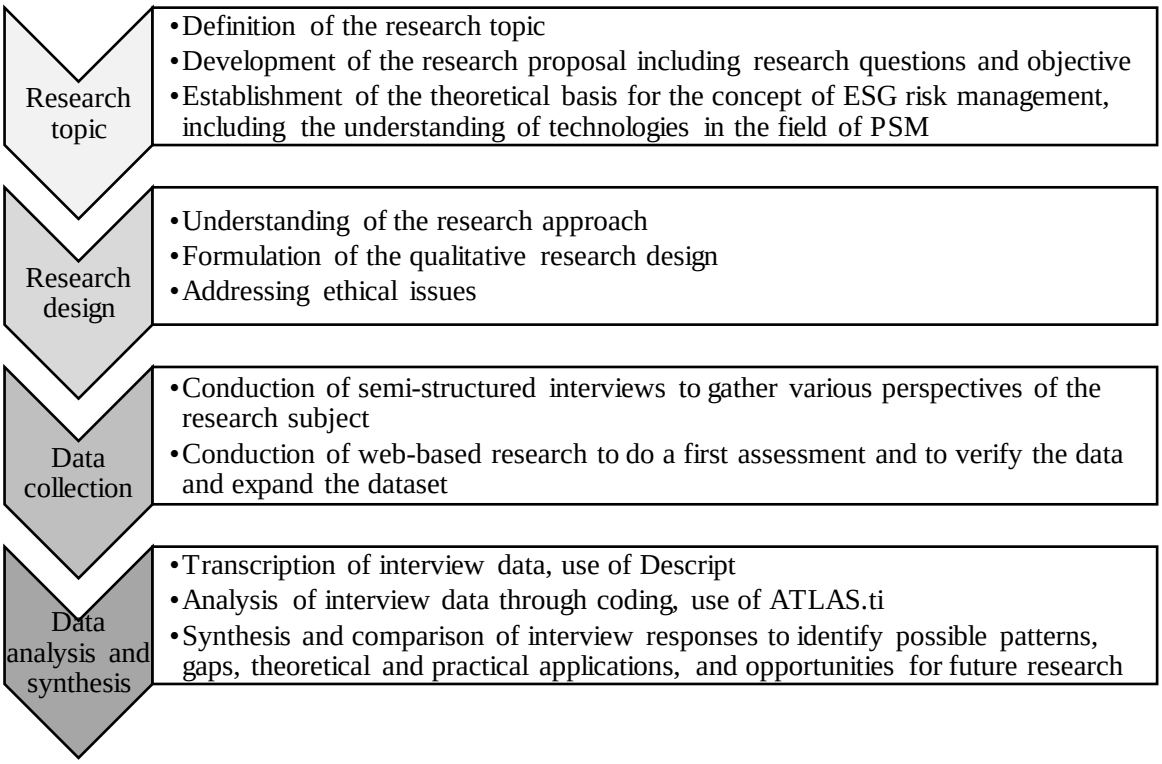


Figure 6. The research design, based on Saunders et al. (2019, p. 12).

3.2 Data collection method entailed semi-structured interviews and web-based research

3.2.1 Conducting semi-structured interviews to gain deep insight into the subject matter

Semi-structured interviews have been conducted, which Saunders et al. (2019, pp. 444-445) describe as a method of qualitative research that allows for flexibility in questioning, which is particularly beneficial when exploring complex or open-ended topics. It has therefore been a suitable approach for this research, also because it offers the respondents the opportunity to reflect on their experiences and perceptions, while being able to ask for deeper insights or clarification of previous answers.[139] Furthermore, the approach is beneficial in situations where it is important to obtain contextual data, for instance when exploring participants' attitudes, opinions or decision-making processes.[140] The interview protocols can be found in Appendices II, III, and IV.

The interviews were conducted digitally via Microsoft Teams and one-to-one, one-to-two or two-to-one. As described by Taherdoost (2021, p. 18), electronic or telephone interviews

[139] See Taherdoost (2021), p. 18.
[140] See Saunders et al. (2019), pp. 444-445.

have the advantage that they, compared to offline face-to-face interviews, can be conducted quicker and need fewer resources.

The interviews have been recorded with the recording function of Microsoft Teams. Additionally, data accounting sheets have been filled in during the interviews, as data accounting sheets are useful for good record keeping and data management.[141] The sheets showed different levels of integration of the main topics, ranging from 'no incorporation' to 'strong incorporation', including a space for explanation. The data accounting sheets can be found in Appendices V and VI.

Before the conduction of the interviews, ethical clearance by the Ethics Committee of the University of Twente has been received.

3.2.2 Contents of the interview protocols and assessment models include current and future perspectives

For this research, the responses of both technology solution providers and PSM experts/buyers have been analysed to gain various perspectives and insights in the subject matter. Therefore, two different but interconnected interview protocols have been created. The interview protocols included several open-ended questions developed to gain insights into various aspects related to the offering and use of I4.0 technology solutions within the field of PSM, particularly about the management of ESG and regulatory risks, as well as the regulatory requirements outlined in the CSDDD. The questions align with the research objectives and have been developed based on the literature review.

The first interview protocol has been created for ESG experts/buyers, to gain information about their current (Industry 4.0) technology usage for (ESG) risk management, as well as to understand their focus on ESG requirements, particularly those outlined in the CSDDD. The experts/buyers were also asked to give their perceptions and expectations of technologies and future technology solutions for ESG risk management. The second group of participants, the technology solution providers, has been interviewed to both gain insights into their perceptions as well as to potentially offer them new perspectives into their customer base' perceptions and expectations. Additionally, insights were gained from technology solution providers to gain deeper insights into their technologies and technological solutions for (ESG) risk management, as well as to find out to what extent the

[141] See Miles et al. (2014), p. 109.

solutions currently, as well as in the future are tailored to the specific needs within the field of PSM, especially related to the requirements included in the CSDDD.

3.2.3 PSM experts/buyers and technology solution providers as interview participants

The selection of participants has been based on several factors. For the technology solution providers, criteria included expertise in addressing PSM risk management and ESG requirements within their technology solution, industry presence, comprehensive purchasing capabilities, and alignment with innovative (Industry 4.0) technologies. For the PSM experts, criteria included their expertise in the field of PSM, as well as their familiarity with ESG risks, the CSDDD, and (Industry 4.0) technological solutions.

Technology solution providers and PSM experts have been invited either via e-mail, LinkedIn, the "Inside Procurement Platform" of the Dutch Association for Purchasing and Supply Management (NEVI) or via phone call, including those involved in the Digital Procurement World in Amsterdam in October 2023. Additionally, efforts were made to connect with PSM experts/buyers by networking with Human Resource Management professionals at the Business Days in Enschede in February 2024. General information about the participants can be found in Tables 4 and 5.

Table 4. Participant information – technology solution providers.

Organi-sation*	Participant*	Role/Responsibilities	Technology solutions/tools	Duration
1	**1**	Chief Sales Officer	Spend analytics	00:49:10
1	**2**	Head of Marketing	Spend analytics	00:49:10
2	**3**	Senior Solutions Consultant	Supply software/digital assessment platform	00:44:07
3	**4**	Senior Sales Executive	All-in-one procurement system	00:27:33
4	**5**	Senior Sustainability Advisor	Sustainability platform	00:45:04
5	**6**	Sustainability Sales Executive	Procurement analytics software	00:48:33
6	**7**	Co-Founder and Managing Director	Carbon management software	00:29:19
7	**8**	Vice President Direct Procurement Strategy	Spend management software	00:35:08
8	**9**	Marketing Manager	Spend management software	00:27:21
9	**10**	Founder	Consulting firm/sustainability software	00:12:00
10	**11**	CEO & Founder	ESG compliance software	00:51:38

11	**12**	Regulatory & Sustainability Expert	Sustainable supply chain data management solution	00:34:34

*Note: For ethical reasons, the names of the participants and their affiliated organisations are not included.

Table 5. Participant information – PSM experts/buyers.

Organi-sation*	Participant*	Industry	Role/Responsibilities	Duration
1	**1**	Auto parts, NEVI	European Head of Category Corporate Services, Community Lead of the NEVI Continuing Personal Development Community	01:02:17
2	**2**	Consultancy/ Procurement Agency	Strategic Advisor/Managing Partner	00:39:50
3	**3**	Business Consulting	Senior Project Manager	00:49:55
4	**4**	Lottery Company	Head of Procurement	00:39:46
5	**5**	Senior Sustainability Consultant	Consulting firm with focus on digitalisation	00:41:03

*Note: For ethical reasons, the names of the participants and their affiliated organisations are not included.

It is important to note that the selection of technology solution providers and experts has been influenced by the availability of public information and the willingness of the organisations and individuals to participate in the interviews.

One of the experts interviewed works as a purchaser in an organisation that falls within the scope of the CSDDD, which has been subject to analysis for this research.

3.2.4 Conducting web-based research for data expansion and verification

To expand and verify the interview dataset of the technology solution providers, web-based research has been conducted. Several technology solution providers have been evaluated based on digital media and documents, including websites, videos, webinars and relevant news sources. Particular attention was given to their technology usage and offering, future plans, as well as their focus on ESG aspects and regulatory compliance. Table 6 shows the assessed technology solution providers.

Table 6. Technology solution providers assessed and verified.

Organi-sation*	Country	Founded in	Nr. of employees	Assessment	Verification
1	Australia	2017	100	Interview	Web-based research
2	United Kingdom	1990	<1,000	Interview	Web-based research

3	Germany	1999	<200	Interview	Web-based research
4	Sweden	2016	<200	Web-based research	Interview
5	Finland	2003	<500	Web-based research	Interview
6	Germany	2021	<50	Interview	Web-based research
7	United States	1995	<5,000	Interview	Web-based research
8	United States	2000	<1,000	Interview	Web-based research
9	Netherlands	2019	<50	Interview	Web-based research
10	Germany	2021	<50	Interview	Web-based research
11	Canada	2010	<1,000	Web-based research	Interview
12	Poland	2011	<50	Web-based research	-
13	France	2007	>1,000	Web-based research	-
14	USA	2000	<200	Web-based research	-
15	United Kingdom	2018	<200	Web-based research	-
16	USA	2005	<200	Web-based research	-
17	Sweden	2016	<200	Web-based research	-
18	USA	1970	>10,000	Web-based research	-
19	Germany	2015	<200	Web-based research	-
20	Austria	2017	<500	Web-based research	-
21	Ireland	2012	<200	Web-based research	-
22	United States	1998	<5,000	Web-based research	-

*Note: For ethical reasons, the names of the assessed organisations are not included.

The technology solutions have been assessed using a maturity model. As described by Becker et al. (2009, p. 213), a maturity model is a tool that can be used to assess the level of, for instance, processes or organisations over time. It usually consists of a series of stages or levels through which an entity evolves from an initial state of little capabilities to a stage of total maturity, with each stage representing an increasing level of capabilities or process performance.[142] In this research, the maturity consists of four dimensions (risk management,

[142] See Becker et al. (2009), p. 213.

ESG integration, compliance with regulations, and future readiness) that are again divided into nine subcategories. The categorisation has been based on the literature review and includes all relevant factors, taking into account the supply risk management model by Hallikas et al. (2004, p. 52; Hoffmann et al. (2013, p. 199) and the ESG requirements as described in Table 2 for this research. The maturity level has been categorised into four stages; basic (1-5 points maturity), emerging (6-10 points maturity), evolving (11-15 points maturity), and advanced (16-20 points maturity). The basic stage reflects a limited focus and minimal capabilities, with processes that are either not in place or only in the early stages of development. At this stage, organisations have a basic approach to risk management processes and stages, and minimal integration of ESG factors, with basic to no compliance with regulations and sustainability. The emerging stage indicates moderate capabilities where some structured approaches are in place but are still limited. Organisations at this stage show a more developed focus on risk management processes and an initial integration of ESG factors. Compliance requirements are met, but functionalities remain basic and there is only a limited focus on future needs and technological developments. The evolving stage represents a well-established approach with strong capabilities and consistent processes. Organisations at this stage have a strong focus on risk management processes, strong integration of ESG considerations into their operations and strong compliance practices. They show strong foresight on future readiness, including an anticipation of change of regulations and the development of technology solutions. Finally, the advanced stage represents the highest level of maturity and is characterised by proactive and comprehensive processes in the dimensions. Organisations at this level show a full integration and optimisation of risk management processes and ESG factors, extensive compliance strategies and advanced technology solutions, also in view of future requirements. Table 7 shows a brief overview of the tested maturity dimensions and their categories.

Table 7. Overview of the maturity dimensions and categories.

Dimension	Category	Explanation
Risk management	Processes	Focuses on how an organisation manages risks systematically, with a focus on the risk management stages.
	Strategies	Involves planning and approaches dedicated to managing risks.
	Tools	Advanced technologies used to manage risks directly and indirectly.

ESG integration	Environmental Integration	Focuses on how environmental concerns, including emissions and waste are incorporated into technology solutions.
	Social Integration	Focuses, among others, on policies on human rights, labour conditions, and social responsibilities, including human trafficking.
	Governance Integration	Involves governing frameworks, including incentive schemes and data protection.
Compliance with regulations	Compliance	Focuses on offering compliance with (newest) regulations and laws, with a special focus on the CSDDD.
Future readiness	Technology Anticipation	Adoption of advanced technologies to ensure sustainability and adaptability for future challenges.
	Updating Compliance	Focuses on offering compliance with the latest compliance requirements and future regulations.

A similar maturity model has been created for the PSM experts/buyers for comparison and to ensure consistency. The maturity models in this research used for external benchmarking.[143] The maturity models can be found in Appendices VII and VIII.

3.3 Assurance of data quality by addressing the validity and reliability of the research

For the assurance of the quality of the research, the reliability and validity have been addressed. Reliability can be referred to as the reproducibility and consistency of data, while validity refers to the accuracy of measuring instruments[144] and analysis used to gather and interpret the data, including the suitability of data for the research.[145]

The participants of the research were all connected to the subject matter in a similar way, and all participants were familiar with the subject. Additionally, the participants have been informed about the subject and its details in the interview, and received the interview protocol several days before the interview. This has been done to increase the credibility, and therefore also the validity and reliability of the research.[146]

Additionally, the semi-structured interviews have been conducted in a one-to-one, one-to-two or two-to-one setting, thereby fostering an undisturbed background in which outside influences could not interfere, thereby ensuring high validity and reliability of the data collected.

[143] See Pöppelbuß and Röglinger (2011), p. 5.
[144] See Carmines and Zeller (1979), p. 17.
[145] See Saunders et al. (2019), pp. 213, 361.
[146] See Saunders et al. (2019), p. 452.

Besides the semi-structured interviews, the web-based research was intended to verify the answers given during the interviews, a method also known as triangulation, thereby increasing the validity of the research.[147] Moreover, web-based research has been used as assessment tool as well as to expand the dataset to provide a more extensive assessment of the technologies available for (ESG) risk management within the field of PSM, thereby increasing the reliability of the research.

To further increase the validity of the research, maturity models have been created for both groups of participants, including the web-based research.

3.4 Interview data analysis through transcription and coding

As first step of the data analysis, the interview records were transcribed into text. The software Descript has been used for the transcription.

After the transcription, the data has been coded. Codes can generally be described as labels used to assign meaning to descriptive or inferential data collected in a study[148], which are often associated with data segments of varying sizes and can range from simple, descriptive labels to more complicated and evocative ones.[149] As elaborated by Miles et al. (2014, p. 86), coding generally takes place in two cycles. In the first cycle, coding begins with the creation of initial summaries of the data segments. The summaries are then grouped into fewer categories, themes, or constructs as part of pattern coding, the second cycle method. For this research, the software ATLAS.ti has been used to systematically and automatically code the received interview data, including the use of AI. After coding the data, within-group comparisons have been conducted to test whether the results within the group of technology solution providers and PSM experts/buyers showed similar results.

[147] See Patton (1999), p. 1192; Saunders et al. (2019), p. 218.
[148] See Saunders et al. (2019), p. 653.
[149] See Miles et al. (2014), pp. 71-72.

4. RESULTS: VARIOUS SCORES ON RISK MANAGEMENT, ESG INTEGRATION, COMPLIANCE WITH REGULATIONS AND FUTURE READINESS

4.1 Risk management: Strong focus on risk stages and strategies, with critical views on Industry 4.0 technology usage

4.1.1 Technology providers show a high level of risk management processes, strategies, and tools

Risk identification

Technology solution providers focus on innovative tools to improve risk identification. During the interviews with the technology solution providers, it became evident that Industry 4.0 technologies are part of their technology solution, with AI being the most frequently used solution. For most technology providers, AI is primarily being used as tool for data enrichment, while others, including technology solution provider 2, use AI solely for data support and recognition.

In addition, many providers rely on external third-party data sources to improve their risk identification processes. These external datasets enable more accurate and extensive risk assessments by including data about spending and sustainability. In addition, through the use of standardised questionnaires and country risk indices, providers can provide an extensive risk identification of suppliers in different countries and regions. Others analyse transaction data and categorise spendings through the use of AI to find potential (ESG) risks in purchasing activities.

However, the solutions also face challenges. Ensuring the accuracy and completeness of data is difficult, especially when many data sources need to be integrated. This is mainly an issue due to the challenge in identifying risks in long and complex supply chains, despite the support of (AI) technologies and customisable tools. This has become evident during several interviews, where the complexity of supply chains, especially beyond the first tiers, has been mentioned. For instance, participant 1 stated that "No organisation right now, regardless of what they tell you, can tell you who the nth tier supplier is. We call BS on any organisation that can do that because it just explodes if you think about it"[150].

Risk assessment

For the risk assessment, technology solution providers offer tools to help buying organisations to cope with ESG risks, including mapping spend data on ESG risks, thereby

[150] Technology solution provider 1, 07/05/2024.

providing a better understanding and classification of the risks. Furthermore, AI has been used to support the detailed spend analysis and coding of cost structures.

Despite this progress, there remain challenges. For instance, adapting risk assessment frameworks to changing regulations requires ongoing effort and adaptability. Moreover, it can be difficult to find a balance between the need for detailed risk assessment and the practical limitations of data collection and assessment.

The limitations of AI include, for instance, the estimation of carbon footprints and ethical issues in supply chains based on incomplete data. If only a small percentage of organisations report their carbon emissions or labour practices, these reports are likely to come from organisations that are making efforts to improve, while the silent majority may not be taking action. The following quote by participant 3 highlights the statement: "You cannot use the data from 10 percent of organisations to make a judgment on the other 90%" [151]. Consequently, using data from a few proactive organisations to generalise across the industry may lead to overly optimistic risk assessments. Therefore, there is a demand for stricter regulation to ensure comprehensive and accurate assessments rather than relying only on AI or other similar technologies.

Risk management

Technology solution providers offer a variety of tools and strategies to manage risk effectively. For instance, technology providers 9 and 11 offer insights into ESG risk and compliance data, as well as improve the understanding of the supply chain and ESG risks by suggesting areas for improvement. These providers essentially consult organisations to better manage their risks and compliance. These recommendations are, for instance, based on spend analysis and sourcing locations. Other providers focus on providing structured data overviews to their clients, who can use that data to implement own risk management strategies. Ultimately, it can be stated that technology solution providers are focused on enabling their customers to react proactively rather than reactively to risks, which, for instance, has been emphasised by participant 9: "Our goal is to allow companies to take action before problems arise, so they are not playing the role of the firefighter but instead preventing the fire from starting"[152].

[151] Technology solution provider 2, 07/05/2024.
[152] Technology solution provider 8, 07/08/2024.

However, risk management is accompanied by challenges. For instance, continuous collaboration and communication within the buying organisation and between stakeholders is required to implement effective risk management strategies. Another challenge is to ensure that risk management can respond both proactively and reactively to new threats.

Risk monitoring

To ensure effective risk monitoring, technology solution providers provide sophisticated tools and capabilities, such as constant updates with new datasets and tools for tracking ESG risks. Some providers, including provider 11, offer platforms that remind buying organisations of risk reassessments and provide guidelines to keep up to date with, for instance, regulatory changes. They also support continuous monitoring through structured data sharing and real-time analytics, allowing the buying organisations to access up-to-date risk information.

However, providing the necessary technologies for continuous monitoring and timely updates can be challenging, as updated information of supply chain developments and therefore often a comprehensive AI technology structure is needed.

In addition, it should be noted that other advanced technologies, including blockchain, have not yet been incorporated in the interviewed organisations. In fact, it has been mentioned that blockchain, although being currently available on the market, is not mature enough to be coping with the increasing concerns regarding (ESG) risks and transparency issues, as not all stakeholders use the same technology infrastructure, highlighted by the following quote by participant 9: "The main reason blockchain has not taken off is that everyone is trying to create their own version. A universal blockchain could work, but getting everyone on board is the problem"[153]. Furthermore, high amounts of relevant data of all supply chain stakeholders need to be included into the blockchain, including payment data and invoices, which is currently not possible to do.

The risk management stages of the technology solution providers assessed through interviews can be seen in Table 8. The general remarks can include both own challenges and difficulties in the technological environment.

[153] Technology solution provider 8, 07/08/2024.

Table 8. Brief overview risk management in technology solutions.

Criteria	Technology solution provider			
	1	2	3	4
Description of (technology) solution	AI-driven spend analytics, Natural Language Processing for supply chain data, taxonomy classification tools. Focus on data aggregation and enrichment.	Digital platform with assessments and audits. Collects data through questionnaires and integrates it with external feeds. Uses AI for document recognition.	Modular platform for supplier management, e-sourcing, and procurement. AI used for spend categorisation, invoice automation, and analytics. External platforms can be integrated for compliance.	Digital platform for supply chain risk screening. Provides risk indices and standardised questionnaires to assess supplier risks. Customisable by sector and regulations.
Risk identification	Uses AI to process unstructured data from ERPs, identifying risks related to spend categories and supplier compliance.	Identifies risks by collecting supplier data via questionnaires and audits. Provides risk profiles with scores based on compliance with regulations and other ESG factors.	Focuses on supplier qualification and automated risk assessments via digital questionnaires. Customisable by sector and product. Continuous process for both new and existing suppliers.	Supports risk screening of supply chains using ESG risk indices and standardised questionnaires. Custom risk assessments can be built.
Risk assessment	Real-time connectivity between buyers and suppliers to assess supply chain risks. Enriches internal data with third-party data sources.	Combines data from audits, questionnaires, and third-party sources to assess risks. Offers compliance scores based on ESG metrics, sanctions, and financial stability.	AI helps to categorise spend and analyse supplier data. Tools provide risk scores based on supplier input and external data. Users can add custom risk metrics.	Helps to prioritise suppliers for risk based on questionnaire responses and external risk indices but does not conduct specific impact analysis. Clients use the results to perform their own risk prioritisation.
Risk management	Compliance tools for supplier onboarding and monitoring, providing automated alerts for expiring certificates and regulatory updates.	Supports suppliers in improving compliance by providing feedback based on scores. Helps suppliers understand how to improve their scores and reduce risk.	Automates the management of procurement processes. AI automates coding and approval of transactions. Allows users to adjust risk management thresholds automatically.	Does not advise on risk mitigation strategies but provides guidance through links to resources. Clients manage risks based on prioritised supplier risks.
Risk monitoring	Continuous risk monitoring via AI-driven tools and integration of third-party data. Focused on updating supplier compliance status.	Ongoing monitoring with dashboards that track supplier performance over time. Flags changes in compliance scores, and alerts for expiring documents and updates in risk profiles.	Provides real-time monitoring and alerts for supplier compliance. Offers automated reminders for expiring documents and risk thresholds. Dashboards allow for ongoing assessment of supplier risk.	Customers monitor their supplier risks via questionnaires and risk indices. They can track responses over time, with reminders for unresponsive suppliers. No automated red-flag alerts, monitoring is primarily client-driven.
General remarks	Difficulty in achieving visibility beyond tier-1 suppliers, limitations in mapping complex supply chains, and the challenges of processing poor-quality data.	Faces challenges in ensuring real-time data accuracy, especially with global suppliers.	AI is mainly used for categorisation and spend analytics, with limited use in complex risk analysis.	Managing complex supply chains and ensuring full supplier transparency across multiple tiers. The platform relies on customers to supply supplier details, and data collection depends on supplier responsiveness.

	5	6	7	8
Description of (technology) solution	Procurement analytics platform with modules for CO2 and ESG data integration. Uses AI for spend classification and dashboards. Integrates external ESG data.	CO2 management system focusing on Scope 3 emissions. Integrates supplier data into carbon footprint calculations. Not positioned as a comprehensive ESG tool but specialises in carbon management. Collaborates with other providers/platforms.	Source-to-pay platform offering procurement tools, supplier management, contract management, and spend analysis. Integrates AI and ML for risk identification and contract management. Works with external risk providers.	Source-to-pay platform for supplier management and sustainability certifications. Focus regulatory compliance, e-tendering, contract management, and supplier emissions (T-1 to T-3). Integration with other solution providers.
Risk identification	Identifies hotspots in CO2 emissions and ESG risks via procurement and spend data. Flags missing data for supplier risks.	Focuses primarily on identifying carbon-related risks through transaction-based analysis. Identifies Scope 3 emissions risks, supplier carbon footprints, and corporate carbon footprints.	Focuses on early risk identification. Identifies supply chain risks using data integration with risk management providers. Offers insights into financial, geopolitical, ESG, and weather-related risks.	Uses AI and supplier data to identify risks. Risk levels are displayed. Focus on emissions and supplier certifications.
Risk assessment	Provides dashboards for CO2 and ESG risk assessments. Assesses risks by integrating procurement and supplier data. Can assess risks based on spending and category.	Combines Scope 1, 2, and 3 emissions data to assess carbon risks in supply chains. Translates spend data into emissions calculations. Uses transaction data, bill of materials, and emission factors to identify risks.	Risk assessments are supported by data from external solution providers. Users can prioritise risks by product group, region, and risk severity. AI and ML assist with supplier selection and contract analysis.	AI-supported assessments with dashboards showing risk levels. Allows clients to prioritise actions based on emissions and certification gaps. Provides an overview of tier-1 to tier-3 emissions.
Risk management	Offers a savings program for carbon reduction, allowing customers to create reduction projects with suppliers. Helps monitor reduction initiatives.	Supports clients in developing carbon emission reduction plans based on identified risks. Provides reduction recommendations based on supplier-specific emissions data.	Encourages customers to create strategies for supplier development. Risk management tailored to product group strategy.	Consulting is often used for this phase. Clients have access to the AI database and an Intelligent Virtual Agent bot.
Risk monitoring	Offers continuous monitoring of ESG data with real-time insights into category or supplier performance. Highlights sudden carbon intensity increases and flags missing data points.	Monitors carbon-related risks through real-time updates. Offers visibility into supplier performance and compliance. Can generate automated quarterly reports for regulatory compliance.	Supplier monitoring is conducted via a classification system. Automates alerts for high-risk suppliers and recommends actions. Continuous monitoring is provided for high-priority suppliers.	Automated certification monitoring and regulation controls. Supplier data is continuously monitored and includes integration of other solution providers.
General remarks	Relies on spend-based calculations for CO2 analysis as supplier-specific data is missing. Suppliers are often not ready to provide full Scope 1, 2, and 3 emissions data.	Difficulty in achieving accuracy in carbon footprint calculations due to inconsistent supplier data. Emphasises precision in CO2 estimates, which can be a challenge with incomplete data.	Inconsistent data availability across the supply chain. Relies on external providers for some risk data.	Risk management requires consultation rather than automated support.

Criteria	9	10	11
Description of (technology) solution	Consulting company focused on sustainability and CO2 footprints. Helps clients with sustainability compliance. Uses AI as a support tool for data processing and provides guidance on compliance requirements.	Modular platform for ESG management. Includes compliance, supply chain sustainability, emissions management, and reporting on regulations. AI is used for automated text generation, for instance for disclosures on regulatory compliance. No direct integration of third-party providers' data.	Provides an AI-driven ESG compliance management platform that integrates real-time public domain screening, supplier surveys, and third-party data.
Risk identification	Provides clients with a system to identify compliance gaps in sustainability. Focused on identifying carbon footprint risks, using AI for data processing.	Conducts risk identification based on the supplier's name, the kind of product, location, and spend volume. Uses indices for country risks. Generates risk assessments across 10 risk categories.	ESG risk identification through two types of approaches: direct supplier engagement via surveys and indirect monitoring via public domain sources.
Risk assessment	AI helps assess CO2 emissions and compliance with sustainability directives. Provides reports on which areas of compliance require improvement.	Product-, solution-, and industry-level risk assessment. Provides highly specific risk assessments. Self-assessment questionnaires are sent to suppliers to validate risks.	Risk is assessed based on the maturity level of suppliers in ESG compliance, using frameworks to identify gaps.
Risk management	Consulting support provided for risk management strategies.	Offers preventative measures for potential risks and remedial actions for imminent risks. Tracks the implementation of these actions and adjusts risk levels accordingly. Automates updates based on supplier feedback.	Offers corrective actions and recommendations to help suppliers improve ESG positioning and compliance.
Risk monitoring	Monitoring involves tracking CO2 emissions over time and reporting changes to compliance status.	Includes grievance management system. Optional media monitoring via external partners for real-time updates. Risk scores automatically updated when new products are sourced from suppliers.	Continuous monitoring through public domain screening and supplier engagement, focusing on updates from adverse media and NGO reports.
General remarks	Incomplete data can hinder accurate CO2 calculations.	Focuses primarily on first-tier suppliers. No current prioritisation of full n-tier transparency due the complexity of managing data across multiple tiers.	Ensuring supplier engagement can be challenging, particularly when relying on public domain sources.

Web-based evaluation of risk management maturity and technology tools

With an average score of 14.2 points for the dimension 'risk management', technology solution providers scored in the 'evolving' stage of the maturity model. The subcategories 'processes' and 'strategies' scored 14.0 and 14.1 points, respectively. The subcategory 'tools' scored highest with 14.6 points. Figure 7 shows the results of the interviews and web-based research per technology solution provider. Appendix IX shows the complete results of the web-based research.

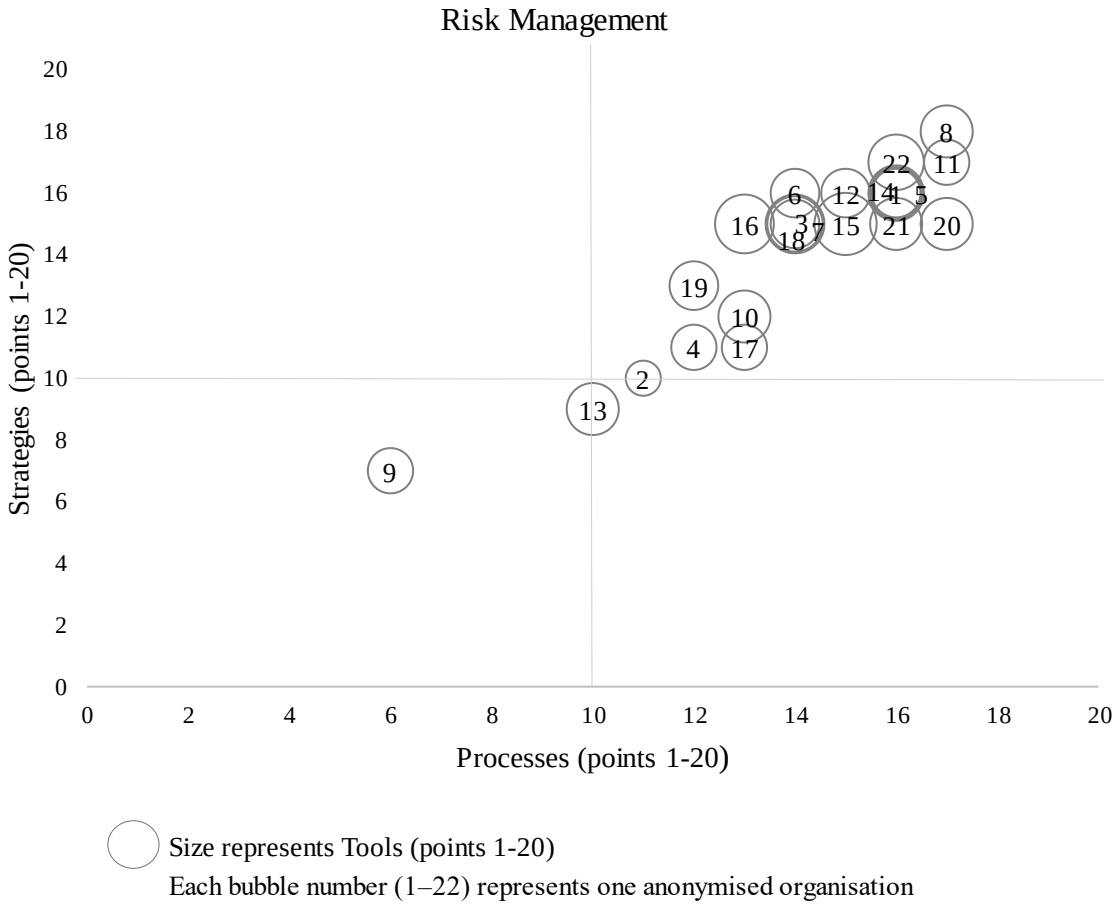


Figure 7. The results of the maturity dimension 'risk management'.

The scores of most technology solution providers emphasise a strong base in risk management processes and stages. This has also become evident during the interviews, where the participants were generally able to discuss the various risk stages their solutions focus on. The subcategory 'tools' scored highest, here a strong focus on newest technologies, primarily AI, is present. All assessed technology solution providers use AI to some extent, either as support tool and/or as integral part of their technology solution, and only provider 15 focuses on the use of blockchain. However, while web-based research showed a broader

adoption of AI, the interviews partly gave a differentiated perspective on its application, ranging from data analysis to support functions, and gave insights into the limitations of the use of AI.

4.1.2 Organisations should focus on risk management stages, advanced technologies and proactive risk management strategies

Risk identification

An initial risk identification is often carried out during supplier pre-qualification and registration processes, often by using strategic supplier evaluations that integrate factors including price, quality, and delivery processes. In addition, these include an understanding of the risks associated with supply chain operations, particularly in terms of geopolitical, environmental, and human rights issues. Other potential risks can be recognised through the use of external data and environmental scanning.

Notably, the CSDDD shifts the focus of risk management from addressing external risks that may harm the organisation to assessing the risks that the organisation's own practices may cause to people and the environment within the supply chain. This reversal of the conventional risk management approach therefore emphasises the impact of business activities on others rather than just protecting the organisation from external threats. This new perspective emphasises the increasing importance of risk identification that takes into account not only the welfare of the organisation itself, but also the social and environmental impact of the organisational practices throughout the supply chain.

Risk assessment

The risk assessment phase involves a deeper analysis of identified risks, using both qualitative and quantitative methods. For instance, some organisations integrate these assessments into their broader risk management processes, while leveraging data from various sources to measure the potential impact of risks. Advanced software tools including AI play an important role, helping to assess risks more accurately and efficiently.

Risk management

The importance of on-site audits has often been mentioned as a tool for risk management. On-site audits ensure that the gathered data is reliable, as certificates and payrolls can be falsified. However, this can become challenging when dealing with a large number of suppliers in different regions. One possible solution for organisations is to work together with organisations in the same industry or sector to develop standardised certifications that

can be widely adopted. This would reduce the need for individual audits, lowering costs while ensuring compliance and consistency across the industry.

Risk monitoring

Continuous monitoring is critical to ensure that risk management strategies remain effective. Organisations should implement continuous monitoring techniques to track supply chain developments and external factors that could affect the risk levels. Monitoring and recognising risks through analysis, including the analysis with advanced technologies such as AI and specific indications is increasingly important, while organisations often underestimate the value of such processes, seeing them as costly and ineffective. In addition, risk monitoring is not just about social and environmental responsibility, but it also offers other benefits to organisations through the creation of improved transparency in their supply chains, as has been emphasised by PSM expert 3: "Companies that had greater transparency, communication, and knowledge within their supply chains likely navigated COVID-19 and other disruptions far better than those with no visibility. In today's volatile and uncertain VUCA world, transparency is more than just risk mitigation"[154].

Technologies and tools for ESG risk management

Several advanced technologies are used within organisations for ESG risk management, including AI and DTs. For instance, DTs are appreciated solutions, as these are accessible solutions that create copies of products or processes to gain transparency within supply chains, in order to monitor and analyse ESG metrics. Additionally, the use of blockchain technologies alongside the use of the IoT has been discussed. IoT sensors play an important role in monitoring ESG-related aspects, including locations, conditions, and temperature, thereby creating transparency of processes within supply chains. That data can be used as input for blockchains, to improve accuracy and reliability. Although blockchain is not widely adopted, also because of the high amount of stakeholders who must work collaboratively to ensure that the technology works in practice, various successful use cases already emphasise its potential impact and is therefore seen as a potential promising technology for the future.

Assessed organisation: implementation of AI and cloud solutions for ESG risk management

The assessed organisation has implemented an AI-driven cloud-based spend management platform, which includes the management of its spendings, finances, supplier relationships, and ESG risks. This platform supports proactive risk management with a strong focus on

[154] PSM expert 3, 10/07/2024.

risk identification and assessment, rather than reactive management. A colour-coded system (red, orange, green) shows the urgency of required risk management testing and actions.

Furthermore, a Product Information Management System has been implemented that acts as a single system that complements product information with insights into, for instance, the product's origin.

Based on the use of advanced technologies and pro-active risk management, the organisation scored within the 'advanced' stage of the maturity model.

4.2 ESG in Purchasing and Supply Managements demonstrates varying integration

4.2.1 Variation in ESG prioritisation among technology solution providers

Varying ESG integration

During the research, the importance of diversity, inclusion, and ethical spending in improving global communities and the environment became more apparent. For instance, the participants emphasised the interconnectedness of the world and the high impact even small changes can have. Participant 2 emphasised that "If we can highlight diversity and inclusion and ethical spending, even by one percent, that's a big impact on global communities and the environment"[155]. Others mentioned the high impact of the purchasing spendings on CO2 emissions and the importance of addressing the spendings to reduce the carbon footprint, which is why the technology solution providers are increasingly focused on sustainable purchasing practices.

However, differences between ESG priorities exist. Some technology solution providers, including provider 6, focus primarily on greenhouse gas emissions reduction when it comes to the environmental factor. Other specific ESG issues, such as chemical control or mercury management are less commonly addressed. Only a few providers emphasise on the specifics of regulations, including the details of the CSDDD. Similarly, in the social and governance aspects, the main focus is on labour rights, child labour prevention, and data security, and less on and mercury management, living wages, or incentive schemes, as these are difficult to assess. It has, however, been mentioned that the Organisation for Economic Co-operation and Development (OECD) will come up with guidelines for living wages, which will be included into the solution of provider 4 to ensure that fair compensation practices are

[155] Technology solution provider 1, 07/05/2024.

implemented within countries and regions where products are sourced. Table 9 shows an overview of ESG integration within the through interviews assessed technology solutions.

Table 9. Brief overview ESG integration in technology solutions.

Technology solution provider	**ESG integration***
1	Focuses on CO2 emissions reduction. Emphasises the importance of modern slavery prevention and cyber security.
2	Strong focus on environmental factors including greenhouse gas emissions and chemical control. Addresses social issues such as labour rights and child labour prevention.
3	Focuses on CO2 emissions. Addresses supplier compliance and risk assessments with environmental and social standards.
4	Emphasises environmental sustainability and human rights within supply chains.
5	Focuses on CO2 and emissions tracking through procurement data. Includes supplier diversity initiatives and responsible sourcing practices.
6	Primarily focused on carbon management and emissions reduction.
7	Strong focus on environmental sustainability, particularly in reducing carbon emissions and monitoring greenhouse gas emissions.
8	CO2 emissions are tracked for suppliers from tier-1 to tier-3. Focuses on sustainability certifications.
9	Focuses on CO2 emissions tracking and carbon management. Helps organisations to meet sustainability goals through consulting support.
10	Strong focus on ESG integration. Modular platform can integrate, for instance, supply chain sustainability and emissions management.
11	ESG integration through supplier engagement (surveys) and third-party screening. Emphasises both environmental and social issues with a monitoring system of media and NGO reports.

*Note: The aspects of ESG risk management listed in this table are not exhaustive. They highlight key aspects, but may include additional environmental, social and governance aspects beyond those explicitly mentioned.

Web-based evaluation of ESG integration among technology solution providers

The maturity model dimension ‘ESG integration’ scored on average 13.6 points, with the ‘environmental integration’ and ‘governance integration’ subcategories scoring highest with 14.0 points on average, followed by the ‘social integration’ subcategory, scoring 12.7 points. Both the interviews and the web-based research assessments showed quite similar results for the ESG specifics, therefore indicating no significant differences in the assessments.

Although technology solution providers scored on average moderately high on the ESG dimensions of the maturity model, high variations between the ESG practices of technology solution providers were evident.

Several providers take a broad focus by addressing multiple ESG practices, while others pay limited attention to many of the social and environmental aspects. The results can be seen in Figure 8.

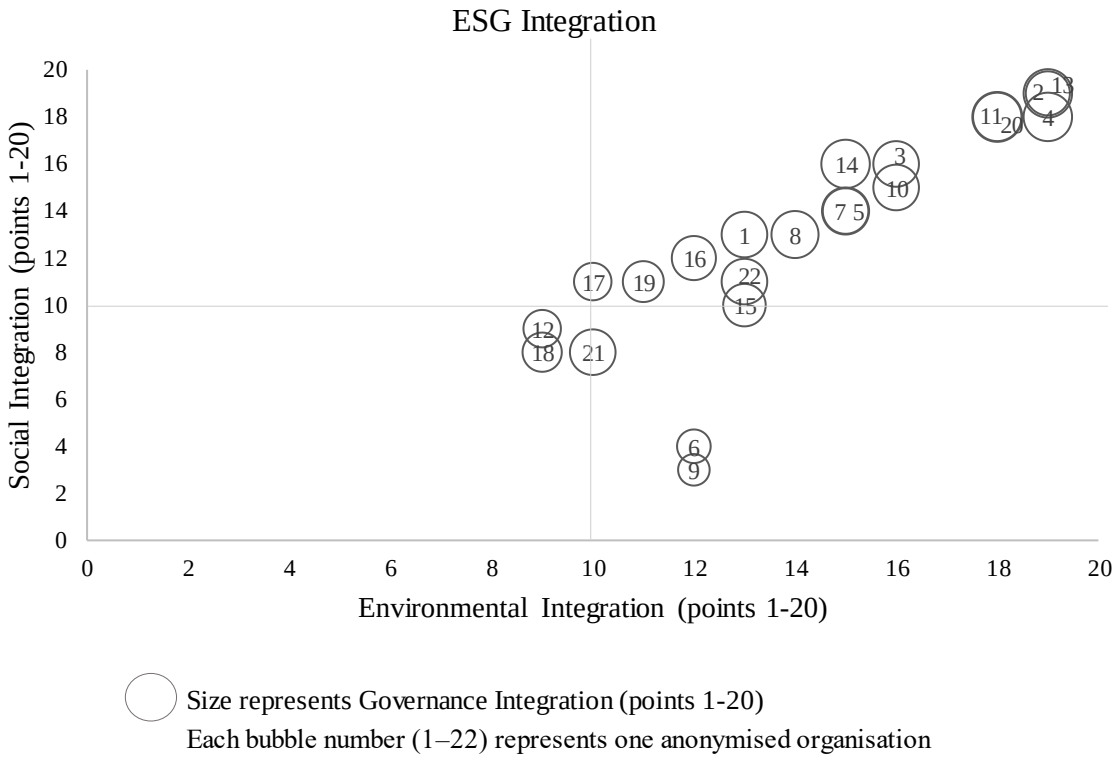


Figure 8. The results of the maturity dimension 'ESG integration'.

4.2.2 Increasing concern among buyers about specific ESG integration

Sector-specific focus on ESG

Although the attention towards ESG within organisations and supply chains is increasing, it remains challenging to consider every ESG aspect as described in regulations such as the CSDDD. Additionally, the PSM experts/buyers, similarly to the technology solution providers, mentioned that the main focus on ESG issues varies by sector. For instance, sectors with high waste generation may prioritise waste management and focus less on other ESG metrics to improve their ESG performance. In addition, organisations may prioritise "quick wins" within their ESG initiatives, which are often handled through signed agreements rather than in-depth management and monitoring. Additionally, measurable

targets are often prioritised, such as labour rights and the reduction of greenhouse gas emissions, as these are relatively easy to quantify and require less resources.

Assessed organisation: strong commitment to ESG practices

The assessment of the organisation however shows a strong focus on numerous ESG aspects in the supply chain, and an increasing commitment to Circular Economy principles. For the environmental part, the focus includes the prevention of exposure to hazardous materials, emissions and discharges of hazardous materials into soil, air and water, sourcing from conflict-free sources, waste reduction, as well as emissions reduction. Furthermore, a strong focus on ethical supply chain management has been mentioned, addressing issues such as the prevention of human trafficking as well as ensuring good working conditions, equal treatment and opportunities in the value chain.

The organisation also established sustainability governance structures, including a Vice President Sustainability and a Sustainability Team that report to the Risk Management Committee, Sustainability Advisory Committee and the Board. Additionally, a Global Supplier Code of Conduct has been established to ensure that the supplier network meets or exceeds policies on human rights, labour practices and environmental standards. The sustainability aspect is integrated into purchasing decisions and requires suppliers to comply to the code in all contracts. Moreover, a risk and sustainability assessment process has been developed in order to gain transparency on supplier performance, with the aim of reducing risks of environmental, ethical, social, compliance, financial, quality, privacy and security aspects.

As all these initiatives already fulfil a large part of the ESG requirement of the CSDDD as described in the maturity model, the organisation scored in the 'advanced' stage of the model.

4.3 Regulatory compliance: Many deviations in compliance among technology solution providers and buyers

4.3.1 Not all technology solution providers focus on compliance with ESG regulations

ESG compliance

Despite an increase in ESG regulations over the years, not all technology solution providers focus on strong compliance with (upcoming) ESG regulations. For instance, some technology solution providers, including providers 2, 4, and 7, are very familiar with the CSDDD and are actively working to ensure their technology solutions align with the

requirements, partly in cooperation with third parties focused on specific ESG integration. Other providers focus primarily on other regulations, with the CSRD and Carbon Border Adjustment Mechanism (CBAM) frequently mentioned. An overview of the compliance with regulatory requirements by the assessed technology solution providers is shown in Table 10.

Table 10. Brief overview compliance with regulations in technology solutions.

Technology solution provider	**Compliance with regulations***
1	Limited focus on CSDDD. Some attention to compliance with ESG regulations through external data.
2	Strong focus on compliance, including CSDDD and CSRD.
3	Moderate focus on CSDDD. Stronger emphasis on CBAM compliance and integrating sustainability certifications.
4	CSDDD and related regulations are integrated into the platform using risk indices and screening tools.
5	Some focus on CSDDD, but the main compliance emphasis is on environmental regulations including CBAM.
6	Primarily focused on carbon-related compliance, especially CBAM.
7	Strong compliance focus on CSDDD and other emerging regulations including CSRD.
8	Limited CSDDD focus. Mainly addresses compliance with sustainability certifications including CBAM and CSRD.
9	Focused on helping clients to achieve compliance with sustainability regulations, including the CSDDD, in particular carbon tracking.
10	Focuses on regulations including CBAM, CSRD compliance and CSDDD alignment to a high extent. Offers a grievance management system in line with the LkSG and CSDDD. Customised compliance reports are based on frameworks.
11	Strong focus on compliance with regulations. The platform integrates international standards to assess compliance maturity.

*Note: The aspects of compliance listed in this table are not exhaustive. They highlight key aspects, but may include additional regulations beyond those explicitly mentioned.

Web-based evaluation of regulatory compliance in ESG obligations

With an average score of 13.9 points, the category scored within the ‘emerging’ stage of the maturity model. The analysis primarily focused on newly implemented and future regulations, including the CSDDD, and the ability to meet the legal obligations. In total, all technology solutions were compliant with at least a few specific ESG regulations. The web-based assessment showed again results similar to the interviews. The results are shown in Figure 9.

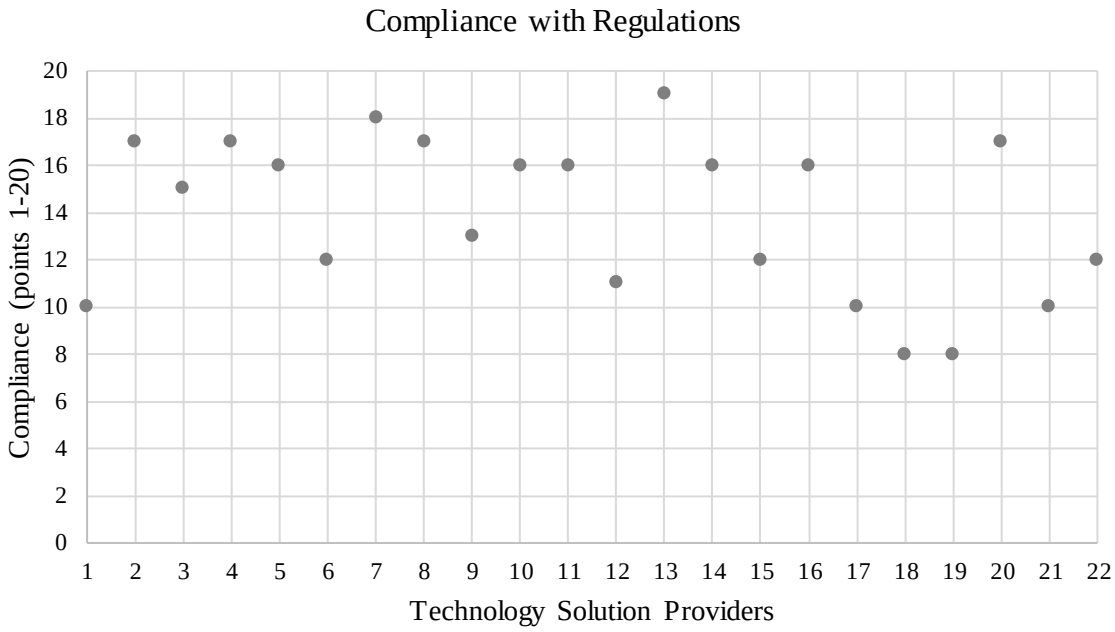


Figure 9. The results of the maturity dimension 'compliance with regulations'.

4.3.2 Within organisations: Balancing early compliance and regulatory uncertainty

Proactive and delayed compliance

Not all buying organisations focus on early compliance with regulations. Some are still in the process of getting the basics in order, such as contract management and General Data Protection Regulation (GDPR) compliance, before focusing fully on directives including the CSDDD and the CSRD, which is particularly receiving significant attention. In addition, some organisations are suffering from a "change fatigue" due to past and current challenges including the COVID-19 pandemic, wars such as the Ukraine-Russia conflict, rising gas and electricity prices (particularly relevant in Germany), and other challenges due to inflation. As a result, the CSDDD may not be given priority.

Besides these challenges, organisations might lack other necessary resources to be able to focus on the CSDDD, as emphasised by participant 5: "Many companies are aware of this big bulk of EU regulations coming, and while they want to get going, they may not have the resources at the moment to start on the CSDDD. This will require both system solutions and internal staff […], but their attitude and knowledge is still pretty good"[156].

At the same time, even organisations with the resources to focus on early compliance with the CSDDD face challenges due to the multiple and developing directives. This can make it

[156] Technology solution provider 4, 19/07/2024.

challenging to determine their exact obligations, leading to significant investment in compliance that may later prove unnecessary, causing some to intentionally postpone taking action until requirements are finalised. For instance, some organisations initially invested significantly in meeting the expected strict requirements of the CSDDD against the German Supply Chain Act (Lieferkettensorgfaltspflichtengesetz, LkSG), only to realise that these efforts may have been premature or mistargeted as the requirements of the CSDDD changed over time.

However, it remains important to focus early on the specifics of newest regulations to ensure preparedness for future compliance requirements. Additionally, early compliance can potentially lead to a competitive advantage, as it avoids last-minute difficulties, fines, sanctions, or loss of licences, and can improve reputation and operational efficiency.

Assessed organisation: strong focus on compliance with new regulations

The assessed organisation focuses strongly on compliance, including the LkSG, the CSRD, but also increasingly the CSDDD. For instance, environmental management processes have been implemented specifically to support full compliance with the strictest new regulatory requirements. The organisation is focused on strictly adhering to laws, regulations and licences. The organisation therefore scored in the 'advanced' stage of the maturity model.

4.4 Future readiness: Strong emphasis on technology integration

4.4.1 Technology solution providers focus primarily on technology development, less on updating compliance

Focus on technologies and compliance

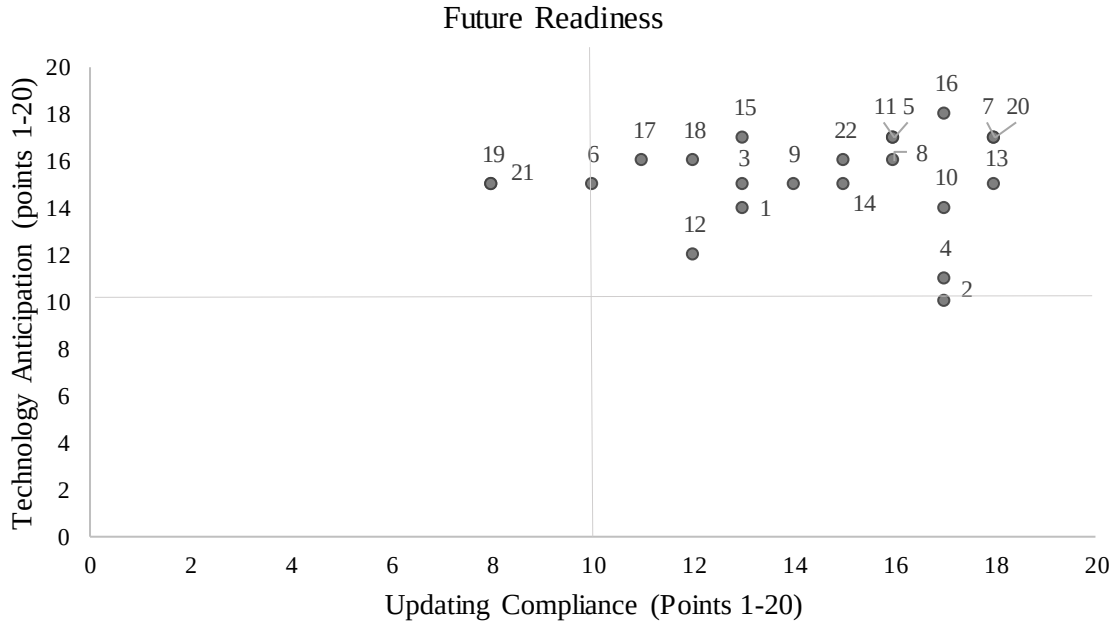
During the interviews, it became apparent that compliance with regulations as well as technology anticipation are important considerations for technology solution providers, as technological advancements and regulatory requirements are rapidly developing. Most technology solution providers invest in the use of advanced technologies for thorough integration into their technology solution, while provider 2 only uses, for instance, AI for data support and will, also in the future, rely primarily on on-site audits, questionnaires, and (digital) desktop assessments without extensive use of I4.0 technologies in order to ensure reliable data.

Participant 3 mentioned that the use of I4.0 technologies for social media data analysis could bring many advantages, although currently not being considered by the organisation. For instance, AI could be effectively used to analyse social media posts on platforms like

LinkedIn and X (former Twitter) to detect business relationships and supply chains, which is still difficult to map extensively. However, legal requirements and compliance considerations around the world need to be thoroughly evaluated before such technologies are implemented.

Web-based evaluation of compliance and technological readiness

Technology development and implementation is an important topic for most technology solution providers. The maturity model dimension 'future readiness' scored on average 14.7 points. The subcategory 'technology anticipation' achieved an average score of 15.1 points and is therefore placed in the 'advanced' stage of the maturity model. The subcategory 'updating compliance' scored lower with an average score of 14.3. Also here showed the web-based assessment similar results to the interviews, with 'technology anticipation' scoring higher than 'updating compliance'. Figure 10 shows the results of the 'future readiness' dimension.



Each point (1–22) represents one anonymised organisation

Figure 10. The results of the maturity dimension 'future readiness'.

4.4.2 PSM experts/buyers integrate advanced technologies and strategic alignment

Importance of technologies and collaboration

During the interviews, several key points regarding the future readiness stood out. First, the importance of cross-functional and end-to-end technology integration has been stressed.

Connecting the purchasing department with other key departments, including finance, is crucial to effectively managing all aspects in the field of PSM, including evolving risks in the field. This approach ensures broad oversight and strategic alignment across the organisation.

Furthermore, the importance of cross-functional collaboration also outside of organisations has been emphasised. Working together and investing in trust and relationships with third parties is crucial to achieve common goals. The further one can influence the supply chain, the quicker and more efficiently opportunities and meaningful outcomes can be achieved.

However, not only is collaboration within and between organisations important, also the importance of good data for effective use of software solutions has been mentioned. Many organisations are overwhelmed by the increasing demands of innovation, sustainability and resilience. To react to these challenges, organisations rely on software solutions that require clear processes and accurate master data to function well. However, without clean and well-structured data, including supplier details and product categories, software solutions, even those driven by AI, will not deliver the desired results. Therefore, effort is required to clean and manage the data before implementing new technology solutions.

Ultimately, the human interaction with technologies is important to adapt and to maintain, particularly in terms of validation and effective utilisation. Job roles are also expected to change in response to the changing technological environment.

Moreover, a balanced approach to the use of various technology solutions is necessary, thereby striking a balance between having a lot of control within just one broad system and leveraging many specific functions within several (new) systems. Some buyers show a Fear of Missing Out (FOMO), leading them towards adopting multiple systems under the assumption that they are all needed. This can result in minimal usage and an increase in unnecessary costs. On the other hand, a substantial part of buyers remains conservative and continues to use long-established systems due to, for instance, budget constraints and a lack of willingness or understanding, and are thereby possibly missing out on benefits of newest technology solutions.

Assessed organisation: focus on upcoming regulations and advanced technology adoption
Finally, the anticipation of future regulations emphasises the interviewed organisation's commitment to future readiness. In addition, the organisation focuses increasingly on advanced technologies, including AI, to automate cyclic processes, thereby focusing on costs

and efficiency. Therefore, the organisation scored within the 'advanced' stage of the maturity model.

4.5 Performance across the maturity dimensions shows high maturity on risk management and ESG integration, partly lacking compliance with regulations

4.5.1 Future readiness is the highest scoring category for technology solution providers

The technology solution providers scored highest on the 'future readiness' dimension with 14.7 points on average. The subcategories 'compliance with regulations' and 'risk management' scored almost equally with 14.0 and 14.2 points on average, respectively. Last scored the subcategory 'ESG Integration' with 13.6 points on average. Considering the average maturity of the technology solutions across all four dimensions, the overall score amounts up to 14.1 points, and therefore in the 'evolving' stage of the maturity model. The results can be seen in Appendix IX. Figure 11 shows the combined scores of the subcategories 'risk management', 'compliance with regulations', and 'future readiness'.

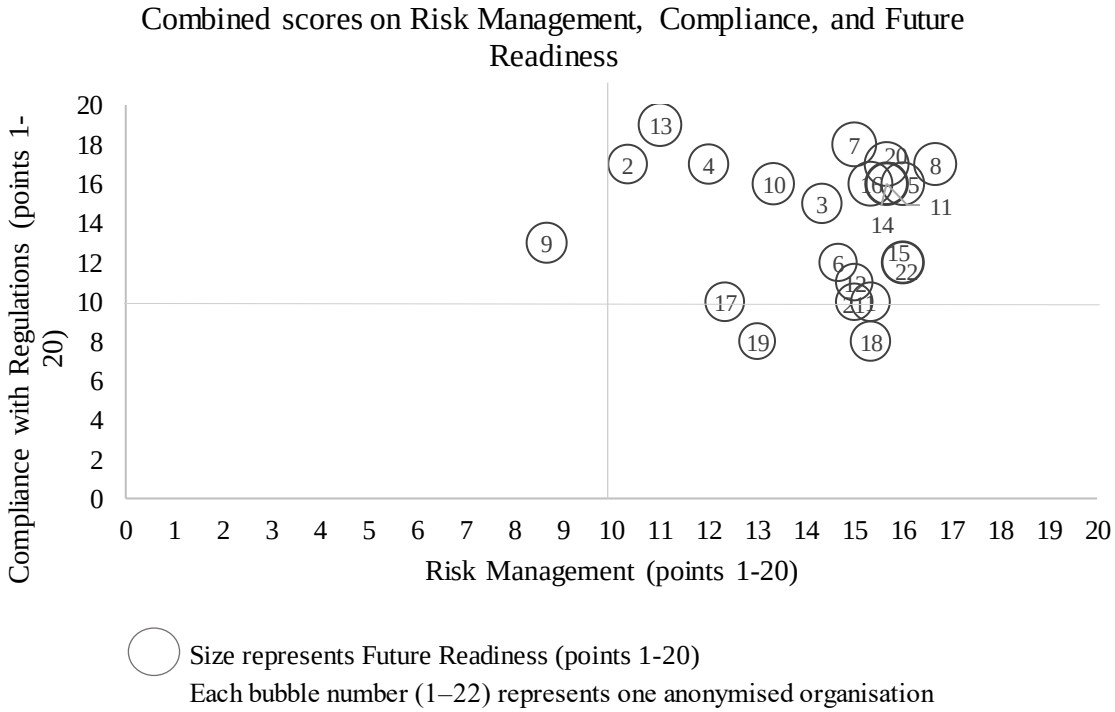


Figure 11. The performance of the technology solution providers across the maturity dimensions 'risk management', 'compliance with regulations', and 'future readiness'.

4.5.2 Organisational focus varies between maturity dimensions

Buyers are increasingly focused on the use of advanced technologies for risk management, with an increasing focus on ESG considerations. However, the commitment to the four dimensions - risk management, ESG integration, compliance with regulations, and future readiness - varies significantly between organisations. While not all organisations are equally committed to all dimensions, the assessed organisation does excel in all related subcategories. The result can be seen in Figure 12.

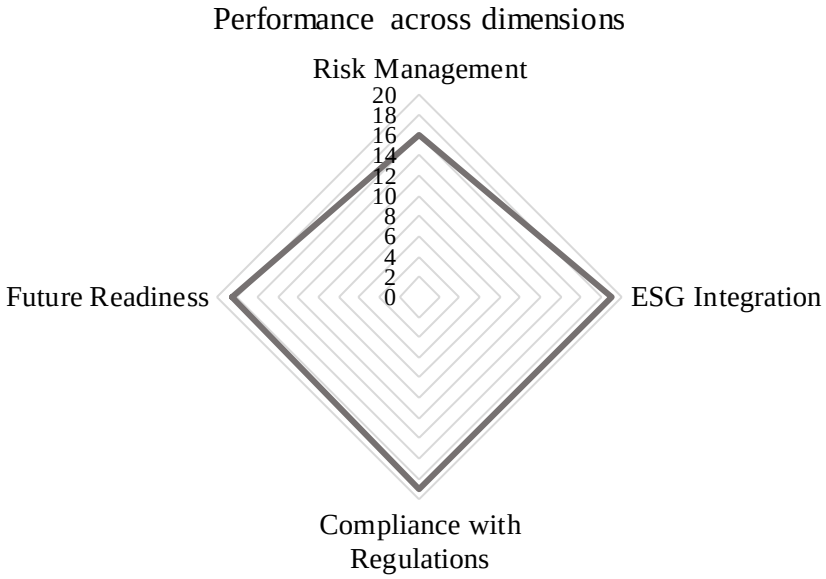


Figure 12. The performance of the assessed organisation across the maturity dimensions.

5. DISCUSSION: TECHNOLOGY SUPPORTED ESG RISK MANAGEMENT IN PURCHASING AND SUPPLY MANAGEMENT

5.1 Strong focus on advanced technologies and ESG integration of both technology solution providers and PSM experts

5.1.1 Challenges and solutions in gaining supply chain transparency for ESG compliance: Focus on advanced technologies

The field of PSM is increasingly focused on ESG related risks, especially in light of the (upcoming) regulations. The CSDDD, which has been one of the main focus points of this research, poses several challenges to organisations.

In particular, the CSDDD shifts the focus of risk management from addressing external risks that may threaten the organisation itself to evaluating the risks that the organisation's own activities may pose to people and the environment within the supply chain. This also complicates the aim for achieving transparency, as organisations not only have to assess their own direct impacts, but also the indirect impacts of their supply chain practices on sustainability.

A significant issue is the challenge of gaining insights into complex, multi-tiered supply chains beyond the first-tier supplier[157] to identify potential regulatory misalignments. This has been frequently stressed during the interviews, where it has been made clear that gaining full transparency is currently impossible to reach for large organisations. Furthermore, the risks of potential legal consequences including fines[158] and increasing compliance costs[159] require a regular analysis of compliance and potential restructuring of the supplier base[160].

In addition, organisations aiming for early compliance face difficulties due to multiple and evolving guidelines, which can complicate the determination of precise obligations and can lead to significant, sometimes unnecessary investments. For instance, some organisations initially invested heavily into complying with the expected strict requirements of the CSDDD against the LkSG, only to find out that these efforts turned out to be premature as the requirements changed. Consequently, organisations that fall within the scope of such regulations seek technological support from technology solution providers.

[157] See Foerstl et al. (2018), p. 204; van Hoek et al. (2020), p. 6.
[158] See Shafiq et al. (2017), p. 1389.
[159] See Felbermayr et al. (2022), p. 47.
[160] See Felbermayr et al. (2021), p. 15.

5.1.2 Predominant use of AI and emerging role of blockchain technology for ESG risk management

Based on the interviews with technology solution providers and web-based research, it has become evident that, from all researched advanced Industry 4.0 technologies, Artificial Intelligence (including its sub-technology Machine Learning) is predominantly used for ESG risk management. For instance, the technology is utilised for data aggregation and support, as well as to map and monitor supply chains. However, AI still struggles to provide the level of transparency needed for the complex, multi-tiered supply chains required by the CSDDD. As has been mentioned during the interviews, AI's tendency to generalise remains a key limitation, especially when dealing with incomplete data from suppliers, which can affect the accuracy of risk management and compliance. In addition, the interview participants emphasised the importance of high-quality data as a foundation for any technological solution. Therefore, even the most advanced technologies may not be effective without reliable input data.

Furthermore, RFID, DTs, and blockchain technology are partly used for (ESG) risk management purposes. However, blockchain technology alone seems currently not to be mature enough for organisations to cope with the rising (ESG) risks in the field of PSM. This aligns with the research of Kopyto et al. (2020, p. 9), who stated that blockchain is still in the phase of development, and the authenticity of inputs cannot be guaranteed. In addition, while blockchain has shown promise in specific use cases, the complexity of global supply chains, where many suppliers may not have the same technological infrastructure, limits its potential to provide the transparency required for adhering with the CSDDD. Its success in single cases does not guarantee a broader application in the field of PSM.

Despite this, blockchain could play an increasing role in the field of PSM for (ESG) risk management in the future.[161] For instance, technology solution provider 15 already focuses increasingly on the implementation of blockchain into its technology solution, and the interviews with PSM experts showed optimism about blockchain's potential. While it has been recognised that blockchain is not yet a widely used technology, it was stressed that blockchain could be promising when combined with other advanced technologies, such as the IoT. This combination can improve the reliability of the input of data, which makes it a more useful tool for gaining transparency and, therefore, in managing ESG risks in the

[161] See Kopyto et al. (2020), p. 9.

supply chain. This perspective is also supported by Kopyto et al. (2020, p. 8), who discussed the integration of IoT with blockchain to enhance transparency in supply chains.

Conclusively, it is important to remain cautious about whether I4.0 technologies will be mature enough to meet future regulatory requirements. While blockchain and AI are promising, their current limitations, especially in handling complex supply chains and data challenges, suggest that they alone will not be able to support organisations in obtaining full transparency requirements, and thus in meeting the CSDDD requirements.

Moreover, the interviews and web-based research showed a strong emphasis on ESG integration into technological solutions, ESG risk management strategies, as well as a focus on future readiness, including the increasing implementation of AI and other advanced technologies and foresight on regulatory changes. However, several technology solution providers do currently not focus on specific regulations including the CSDDD. This could, however, be subject to change within the upcoming months as the regulation is new and not yet in force.

5.1.3 Improving processes: The role of third-party data, early ESG integration and best practices

The emphasis on the importance of working with third parties aligns with the statements by Epstein (2023), a digital procurement expert who was mentioned during one of the interviews. She spoke at the Supplier Experience Live Conference in Amsterdam, discussing the importance of improving supplier relations through interactions and distribution of data. She stated that "third party data exchange is the key to the future"[162], and emphasised the importance of centralised data management in a cloud to improve data intelligence and insights, also for improving responsiveness towards changing risks and ESG requirements.[163]

In addition, it can be assumed that, in the future, an increasing number of emerging solutions will be acquired through Mergers and Acquisitions (M&A), which will enable larger technology solution providers to offer comprehensive solutions, for instance in the area of ESG risk management and the integration of the required sustainability targets.

Moreover, the research contributes to the academic discussion about the influence of advanced technologies on job roles and capabilities within the field of PSM, as well as the

[162] Epstein (2023).
[163] See Epstein (2023).

importance of third-party data integration for improving supplier relationships and supply chain transparency. The digital transformation requires not only adaptation to new technologies, but also differentiation of the best tools for (ESG) risk management. Despite the availability of many technology solutions, selecting the right tools and integrating them with existing systems remains a challenge. Table 11 shows the best practices of the technology solution providers across the four dimensions – risk management, ESG integration, compliance with regulations, and future readiness, based on the web-based research and the interviews.

Table 11. Best practices of technology solution providers across the four dimensions.

Dimension	**Best practices**
Risk management	Gaining transparency in supply chains up to third-tier suppliers.
	Utilising blockchain for improved supply chain transparency.
	Automating risk assessments with AI for real-time monitoring and risk visibility across supply chains.
	Promoting collaboration between organisational departments for aligned risk management strategies.
	Implementing continuous monitoring to identify emerging risks.
	Automating purchasing tasks and improving strategic sourcing, enriched with ESG and risk data.
	Integrating third-party data sources for improved risk management.
ESG integration	Automating ESG data management, regulations, and reporting, embedding ESG scores into supplier profiles.
	Utilising AI-driven ESG scoring to evaluate suppliers.
	Integrating comprehensive ESG metrics beyond carbon emissions.
	Aligning ESG practices with global frameworks for consistent benchmarking.
	Conducting on-site ESG audits for improved data reliability.
	Encouraging supplier transparency with tools for automated feedback and compliance reporting, as well as proactive self-assessment of suppliers.
Compliance with regulations	Offering automated compliance monitoring systems to track regulatory adherence (including certificate expiry alerts, regulatory updates).
	Offering continuous auditing via dashboards and (real-time) risk profiles to quickly identify and address non-compliance.
	Leveraging real-time data (including adverse media, sanctions lists) for proactive compliance management.

	Integrating current and upcoming regulatory requirements (especially CSDDD, but also CSRD, CBAM, and others) for continuous alignment with ESG standards.
	Providing ongoing supplier support through training, consult, and corrective action plans to maintain compliance.
Future readiness	Utilising AI and ML to predict potential future risks and regulatory changes.
	Ensuring adaptability to evolving regulations.
	Ensuring real-time risk identification and monitoring for risk management in complex supply chains.
	Planning for emerging technologies (including IoT and potentially blockchain) to enhance supply chain transparency and (ESG) risk management.
	Prioritising data quality for risk management and compliance, with regular auditing and verification processes to support the reliability and effectiveness of AI and other tools.

5.1.4 Broad versus niche providers: Balancing risk management, ESG, compliance, and future readiness

The web-analysis and interviews show insights in the performance of technology solution providers across the four dimensions. The average scores of technology solution providers indicate a developing maturity, with a differentiated focus on ESG integration, scoring lowest, while future readiness, scoring highest, already indicates a positive development especially for technology anticipation.

A key insight of the analyses is the correlation between ESG performance and regulatory compliance. Providers that score high on ESG integration, especially in environmental and social areas, tend to perform well in terms of (future) compliance as well. For instance, technology solution providers 2, 4, 11, 13, and 20 show a strong alignment between ESG performance and compliance with regulations. This correlation makes sense, as a broad focus on various ESG aspects is already an important step towards providing technology solutions that also adhere to the multiple sustainability-related regulations in the field of PSM.

Another observation is the consistency across categories in a group of solution providers that perform well on risk management, ESG integration and compliance. Technology solution providers including 5, 7, 8, 11, and 20 offer comprehensive solutions that integrate risk management, ESG, and regulatory compliance, and seem well positioned to deal with future

challenges. Their ability to offer comprehensive platforms, including the integration of third-party data, makes it ideal for organisations or industries with strict regulatory requirements that are also looking for integrated risk management systems and aligned processes.

On the other hand, there are technology solution providers that perform less well in some dimensions, such as providers 6 and 9. These providers do not excel in broad aspects of ESG, but focus on innovation in specific areas or sectors, such as carbon emission reduction. Technology solution provider 12, on the other hand, focuses less on ESG in general but performs well in the risk management dimension. Therefore, these technology solution providers take a niche position in the market, and appeal to organisations that prefer specialised solutions for specific challenges.

5.2 Theoretical contributions: Understanding the role of technology solutions in ESG integration and compliance, risk management and their development

5.2.1 ESG integration: Opportunities and challenges

This research is a starting point for understanding the use of advanced technologies, ESG considerations and compliance with new regulations, including the CSDDD, within organisations and technology solutions. An early integration of ESG aspects into corporate strategies has shown to be crucial not only for achieving compliance, but also for gaining competitive advantage. This has also been supported by recent research. For instance, Hsu et al. (2022, p. 14), who studied the influence of CSR on supply chains, found that CSR not only reduces risks and improves the reputation of organisations, it also adds significant value throughout the supply chain. This is emphasised by the following quote: "By taking the necessary social, economic, and environmental actions, CSR is not only a determinant for strategic competitiveness from the firm perspective but also an undergoing evolution toward achieving ever greater importance and better value added to the supply chain"[164]. This includes the minimisation of errors by implementing intelligent risk management and sustainable management systems.[165]

However, current literature is primarily focused on ESG aspects and integration in supply chains, as well as risk management, but less on the combination of these factors. ESG compliance, especially with the CSDDD, turns out to be extremely challenging for both buying organisations and technology solution providers. Despite the advancements in technologies and risk management processes, ensuring environmental and social

[164] Hsu et al. (2022), pp. 14-15.
[165] See Hsu et al. (2022), p. 14.

sustainability through gaining transparency within supply chains remains complex. This is in line with the research by Foerstl et al. (2018, p. 215), who stated that, despite the use of specific information processing mechanisms, preventing sustainability misconduct in supply chains remains challenging due to cost and complexity factors, especially beyond the first-tier suppliers.

5.2.2 Technological solutions for ESG compliance include AI and blockchain

Kalaiarasan et al. (2022, p. 8) responded to the challenge of creating transparency in supply chains and developed the supply chain visibility framework, which shows the antecedents, drivers, barriers and challenges, and effects for promoting supply chain visibility, with blockchain being one key antecedent.

However, the interviews made it clear that while blockchain holds promise for improving visibility to some extent, it also has its own barriers and challenges that need to be tackled before it can promote supply chain visibility on a larger scale. Considering that AI and blockchain technology also come with their own limitations is therefore important, as emphasised by Kopyto et al. (2020, p. 8).

Notwithstanding, the use of AI, including its sub-technology ML for the management of risks and data quality for further use cases, has been frequently mentioned. This is in line with the research by Spreitzenbarth et al. (2024, p. 14), who emphasised the importance of data-driven decision-making for risk management, as well as decision-making on sustainability with the support of AI and ML tools.

However, it should be noted that experts are cautious about over-reliance on these technologies. As elaborated by Spreitzenbarth et al. (2024, p. 14), some experts see AI and ML as tools to improve human decision-making, while others favour autonomous decision-making of these technologies that operate independently, allowing humans to focus solely on oversight.

5.2.3 Technological innovation: Balancing between automation and augmentation

The findings by Spreitzenbarth et al. (2024, p. 14) can be complemented to the research by Colombo et al. (2023, p. 11), who researched digitalisation in the field of PSM and made a distinction between automation and augmentation for technological innovation approaches. They argue that automation increases efficiency by replacing human tasks and increasing decision-making autonomy, while augmentation expands the strategic responsibilities of procurement professionals.

This research reflects this distinction in the risk management stages. For instance, the findings show that the risk identification is closely aligned with automation, as the use of AI and advanced datasets enables systematic data collection, processing, and analysis or large amounts of data, thereby increasing efficiency and accuracy, without the need of human intervention. On the other hand, risk assessment is aligned with augmentation. For instance, AI technologies are used to map spend data to ESG risks and to assess potential risk impacts. These technologies 'augment' human judgment by offering enriched data insights that enable more accurate assessment of the ESG risks. Risk management is also linked to augmentation, as AI can support ESG risk management recommendations and decisions by providing insights and suggestions based on complex data analysis. Finally, the risk monitoring stage is linked to automation, as advanced technologies can support real-time data tracking, while offering an overview of potential ESG risks. This, in turn, enables quick responses to changes and ensures compliance with regulations.[166]

5.2.4 Innovation of technology solutions leads to changing job roles

As technology solutions develop and become increasingly integrated into PSM processes, their impact reaches beyond operational efficiency and extents to changing job roles. This is in line with the research by Kipper et al. (2020, p. 1615), who stated that technological innovations require flexibility and adaptability of workers to keep up with rapid changes in the field. In a similar vein, Spreitzenbarth et al. (2024, p. 16) mentioned the importance for future purchasers to have both expertise and the right technological tools. In addition, the importance of new job roles for the changing technology landscape within the field of PSM, as researched by Delke et al. (2023, p. 13), has been validated during the interviews.

Furthermore, while technology solution providers may not specifically focus on ESG aspects in their technology solution, their focus on transparency and third-party risk management could already support ESG to some extent. Promoting transparency in supply chains could, for instance, help buying organisations to better understand what is taking place in their supply chains, making it easier to identify potential misconducts or other related problems.

5.3 Practical contributions: Leveraging best practices and advanced technologies

5.3.1 Adopting best practices and ensuring strategic alignment in technology solutions

The findings suggests that while many technology solution providers have established effective processes within their technology domain, there remains an opportunity for those with lower scores to improve their practices through adopting best practices from the better

[166] See Colombo et al. (2023), p. 11.

performing providers. This is particularly evident in Table 11, which includes best practices of technology solution providers across the dimensions of risk management, ESG integration, compliance with regulations, and future readiness. Understanding these aspects can also help buying organisations in choosing solutions that match their strategic objectives and operational needs.

In order to take advantage of the technology benefits to the fullest, it is crucial for buying organisations to have a strong focus on technologies and to ensure that they align with both strategic objectives and operational requirements. In addition, buyers should avoid adopting multiple systems unnecessarily or holding on to outdated systems to effectively make use of (newest) technology solutions. Considering the roles and responsibilities of workforce and ensuring that functions are adapted to ensure effective use of new technologies is also important.

5.3.2 Improving purchasing practices through technology solutions

Not only can a focus on technologies improve (ESG) risk management, increase resilience[167] and regulatory compliance, it can also lead to significant improvements in the efficiency and effectiveness of purchasing processes. According to Herold et al. (2022, pp. 435-436), a focus on digitalisation can reduce organisational costs, improve the management of supplier relationships, improve product quality and enable more sustainable practices, which can possibly result into competitive advantages.

Furthermore, the research provides insights for buying organisations into the extent to which technology solutions focus on risk management strategies, advanced technology usage, ESG integration, as well as compliance with regulations. In addition, the future anticipation can help to gain an understanding of future possibilities and support for organisations.

5.3.3 Improving collaborations and data reliability for success

The research shows that technology solution providers should focus on building platforms that enable better communication and collaboration between supply chain stakeholders, especially in times when many emerging supply chain scenarios arise, including fast-changing regulations and technology advancements. In addition, technology solution providers focussing on the development of a comprehensive (ESG) risk management solution/platform should consider the inclusion of third-parties to bundle data and

[167] See Herold et al. (2022), p. 436.

knowledge to provide an extensive solution to buying organisations, while focusing on own competencies.

Reliable data is essential as it forms the basis for accurate assessments and informing decision-making. When assessing risks based on ESG data, for instance, the quality and reliability of that data is important to ensure meaningful insights and outcomes. It is important to remember that even supporting technologies such as AI are not always reliable and may overgeneralise findings.

Therefore, it is crucial for both technology solution providers and buyers to keep pace with regulatory and technological developments. The research emphasises the importance of continuous adaptation and improvement to meet changing regulations and to take advantage of new technological opportunities, while the researched organisation scoring high on all aspects - risk management, ESG integration, compliance with regulations, and future readiness - might serve as a benchmark. In addition, the research emphasises the relevance of fostering relationships with suppliers through effective data management and collaboration.

6. LIMITATIONS AND FUTURE RESEARCH DIRECTIONS TO INCREASE RELIABILITY AND VALIDITY

This research recognises several limitations that could impact the results and interpretations. For instance, the low response rates resulted in a low reliability[168]. As previously mentioned, the selection of both technology solution providers and experts has been influenced by the willingness of organisations and individuals to participate in the interviews. Despite efforts to engage with a broad list of market participants, including prominent names in the ESG/risk sector, a certain amount of organisations declined to be interviewed or has not responded to the interview requests. Therefore, the web-based research has been conducted to increase the validity of the research. However, this has only been possible for the various technology solutions, not for the analysis of opinions and practices of PSM experts/buyers.

In addition, measurement bias has been a considerable concern, especially in the web-based research, because publicly available information may be tailored to attract potential customers, thereby skewing the results of the research.[169] In addition, interviewee bias (also known as response bias) can further have complicated the research process, as semi-structured interviews, which are focused on seeking explanations, can be intrusive as interviewees may withhold sensitive information, which results in incomplete or socially desirable answers.[170]

Moreover, the data analysis has been conducted by only one single person, which could have led to individual bias. Investigator (or analyst) triangulation, which involves two or more analysts, would potentially have reduced bias and improved data reliability and validity by enabling independent analysis and comparison of findings.[171] Addressing such biases in future research is therefore important in order to achieve more accurate and generalisable results.

Furthermore, small differences in assessment models have been noticeable. The web-based assessment gave a more positive impression of the use of advanced technologies within technology solutions, due to a more shallow assessment, while the interviews gave a better and more thorough picture of how technologies are integrated into solutions and where limitations still exist.

[168] See Saunders et al. (2019), p. 363.
[169] See Saunders et al. (2019), p. 366.
[170] See Saunders et al. (2019), p. 447.
[171] See Patton (1999), p. 1195.

Therefore, a more sophisticated maturity model could be of interest for further research. As for this research only a simplified maturity model has been created for comparison purposes without the aim for refinement that is required for broader benchmarking purposes, it could be of interest to increase, for instance, the number of dimensions and subcategories.

Additionally, the dimension 'future readiness' in the maturity table should be tested again shortly before or after the official implementation of the CSDDD. As the CSDDD is a new directive, it might be the reason why technology solution providers currently do not focus strongly on the aspect.

Future research could expand on the integration of ESG aspects by considering the broader financial impacts. For instance, by examining the steps organisations are and have been taking in the area of ESG and CSDDD and comparing their annual figures over time, it might be possible to research the extent to which organisations engaging in ESG initiatives show better financial performance than those that do not. This could provide insights into the benefits of (early) ESG and CSDDD efforts and compliance, building upon this research as well as the findings of Hsu et al. (2022). In addition, future research could explore the extent to which SMEs are focusing on ESG and advanced technologies, taking into account the changing regulatory environment that may also increasingly require ESG compliance for their PSM practices in the future.

Implementing processes to integrate ESG requirements, as required by the CSDDD, is important for organisations that want to comply to the changing regulations. However, the challenge is to identify the most effective methods for implementing these processes into existing operations. Future research could examine best practices for implementing CSDDD requirements, thereby focusing on how organisations can structure their processes to ensure compliance, while maintaining operational efficiency.

In combination with the process implementation, the creation of a suitable work environment is critical. Following the research of job roles and capabilities (e.g. Kipper et al. (2020); Delke et al. (2023); Spreitzenbarth et al. (2024)), it is important to examine which organisational environments and cultures best support the integration of ESG principles.

In regard of the technology solution providers, future research could examine the role of (generative) AI in assessing ethical practices within supply chains, focusing in particular on strategies to overcome the challenges posed by incomplete or biased data. Understanding

how AI can be enhanced to provide more accurate insights could be important to improving ethical compliance across all industries. In addition, further researching the providers' business models, including stand-alone solutions, niche-products as well as collaborations could be useful to examine the variety of solutions currently existing in the market, their expected developments, as well as their success and value to customers. This could be an interesting starting point for future research. This also includes the aforementioned trend of M&A, where organisations aim to expand or consolidate their solutions by either acquiring or merging with other organisations. The maturity of the solutions can determine whether they are suitable for acquisition or other strategic partnerships. Future research could therefore provide important insights into market and maturity developments, as well as innovation trends.

Another promising future research direction could be to evaluate the financial impact of implementing the OECD living wage guidelines on global supply chains, as well as how these standards might affect cost structures and supplier selection. Table 12 summarises the future research descriptions and their corresponding research questions.

Table 12. Possible future research topics.

Research description	**Research questions**
Impact of transparency on ESG	What are the direct and indirect (ESG) benefits of increased transparency in technology solutions?
Exploring the financial impacts of early CSDDD requirements integration in organisations	How do early CSDDD requirements integration initiatives correlate with the financial performance of organisations over time?
Comparing the benefits of early ESG efforts and compliance	What are the operational benefits for organisations that engage in early ESG efforts compared to those that do not?
Examining the focus of SMEs on ESG and advanced technologies due to changing regulations	To what extent are SMEs adapting to ESG requirements and advanced technologies, and how are they preparing for potential regulatory changes?
Impact of limited data on AI insights	How do the limitations of AI in estimating ethical practices affect the accuracy of sustainability reporting in global supply chains? What strategies can be employed to improve AI accuracy in assessing ethical practices within supply chains?

Impact of business models and collaborations on ESG risk management success and customer value	How do different business models among technology solution providers for ESG risk management impact their success and market position? How do collaborations between (ESG) risk management technology solution providers influence the overall value delivered to customers compared to independent solutions?
Factors influencing the maturity of risk management solutions in the field of PSM	What are the key factors influencing the maturity of (ESG) risk management solutions in the field of PSM? How does the maturity of a solution affect its suitability for acquisition or strategic partnerships?
Trends in M&A among technology solution providers in the field of PSM	What trends can be observed in mergers and acquisitions of technology solution providers within the field of PSM?
Impacts of the implementation of OECD living wages guidelines	How does the implementation of OECD living wage guidelines impact the overall cost structure and supplier selection in global supply chains?
Processes for implementing CSDDD requirements	How can organisations structure and implement processes to effectively integrate CSDDD requirements?
Working environments supporting ESG and CSDDD integration	What organisational working environments and cultures are necessary to support successful implementation of ESG and CSDDD processes?
Supplier perspectives on CSDDD compliance	How do suppliers perceive and respond to the challenges and opportunities presented by their customers' adherence to the CSDDD?

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APPENDIX I - REFERENCE ARCHITECTURE MODEL INDUSTRY 4.0

While there are various interpretations of Industry 4.0, there is a widely accepted model referred to as the Reference Architecture Model Industry 4.0 (RAMI4.0), shown in Figure A.1.

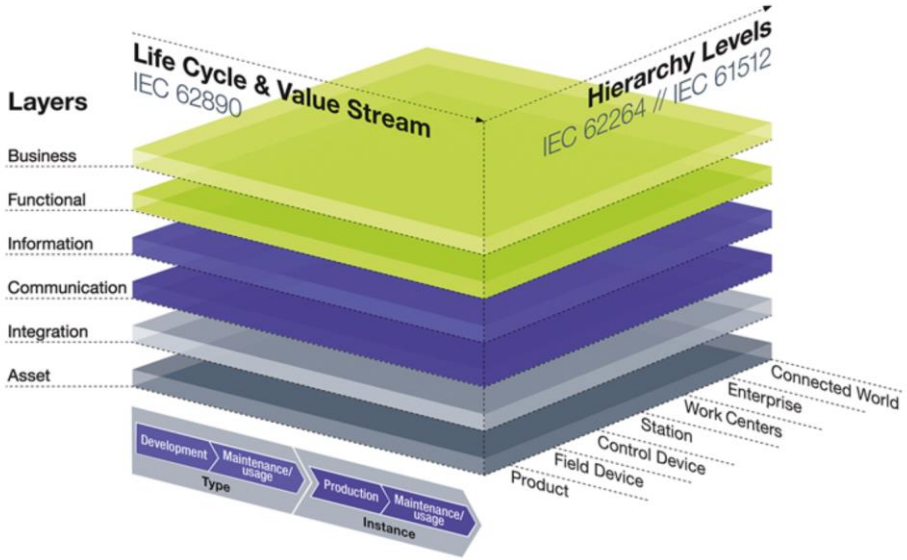


Figure A.1. The Reference Architecture Model Industry 4.0 (Heidel et al. (2017, p. 41)).

The three-dimensional service-oriented architecture model has been developed to describe the topic of Industry 4.0 in a structured way, thereby making discussions between all I4.0 participants understandable and coherent.[172] The first axis or dimension shows the Hierarchy Levels, which represent the different functions throughout the network, ranging from smart products to the connected world. The second axis shows the product and facility life cycle of the Life Cycle & Value Stream, starting with the preparation of construction plans and concluding with facility management. The third axis represents the various Layers, which show the different machine properties[173] ranging from components of the digital world (business processes, functions, data, communication, and digitalisation) to real-world components (digitalisation and physical things).[174]

[172] See Heidel et al. (2017), p. 41.
[173] See Xu et al. (2021), p. 532.
[174] See Heidel et al. (2017), p. 41.

APPENDIX II – INTERVIEW PROTOCOL INTRODUCTION

Introduction to research

My name is Eva Nelissen, and I am a Master student studying Business Administration at the University of Twente. For my research, I am investigating the use and implementation of (Industry 4.0) technologies within the field of Purchasing and Supply Management. Specifically, I am focused on the management of risks related to Environmental, Social, and Governance (ESG) regulations, including compliance with regulatory requirements. Thank you for participating in this interview, your insights will be very helpful for my research!

Privacy, confidentiality, and anonymity

1. Before we proceed, do you consent to me documenting this conversation, either by recording and/or transcribing it?

Additionally, I want to assure you that any information you share will be treated confidentially and used exclusively for research purposes. You are free to end the interview at any time.

General introduction

2. Could you please state your name?
3. What organisation do you represent?
4. What is the size and industry of the organisation you represent?
5. Could you provide a brief explanation of your role or responsibilities within the organisation?

APPENDIX III - INTERVIEW PROTOCOL PSM EXPERTS/BUYERS

Interview – PSM expert/buyer

Current Risk Management

I am interested in risk management in the field of Purchasing and Supply Management (PSM).

1. What strategies or approaches does your organisation employ to manage risks in the field of Purchasing and Supply Management?

I am also looking into the various stages of risk management. The four stages I used for my research include risk identification, assessment, management, and monitoring.

- The process of risk **identification** involves the recognition and understanding of potential uncertainties or sources of risks.
- Risk **assessment** involves the evaluation of the identified risk factors based on their probability and consequences and prioritising them.
- The **management** of risks includes strategies such as risk taking, transfer, elimination, minimisation, and detailed analysis to address and manage potential risks.
- Risk **monitoring** can be defined as the use of indicators to regularly evaluate the likelihood of, and possible changes within the occurrence of risks.

2. Please provide insights into how PSM risks are identified, assessed, managed, and monitored within your organisation.

Current Focus on ESG Factors and Compliance

3. Could you please specify the extent to which your organisation focuses on Environmental (E), Social (S), and Governance (G) (ESG) factors within its Purchasing and Supply Management department?

I am also interested in the new Corporate Sustainability due Diligence Directive (CSDDD), issued by the EU. The CSDDD requires organisations that fall within its scope to integrate due diligence into their corporate policies and supply chains to identify, prevent, and mitigate potential and actual adverse impacts on human rights and the environment.

4. To what extent does your organisation focus on compliance with the objectives of the CSDDD?

Technology Usage for Risk Management and ESG

5. Which technologies or software solutions does your organisation currently utilise for overall risk management within Purchasing and Supply Management?
6. Additionally, which specific technologies or software solutions are employed for ESG risk management in Purchasing and Supply Management?

Expectations from Technology Solutions for ESG Compliance

7. What functionalities or capabilities do you think a technology solution should possess to effectively meet sustainability requirements, taking into account possible future regulations (including the CSDDD)?
8. Please also differentiate between the expectations for addressing Environmental, Social, and Governance aspects within the changing regulatory environment.

Future Expectations from Technology Solutions

9. Looking ahead, what are your organisation's expectations regarding the role of Industry 4.0 technologies in addressing ESG risk management concerns in Purchasing and Supply Management?
10. How do you anticipate these technologies evolving to meet future ESG compliance and risk management needs? Please also provide a timeframe.

Additional questions – PSM expert

Focus and Challenges of Technologies and Technology Solutions

11. How would you describe the current level of adoption of Industry 4.0 technologies among buyers within Purchasing and Supply Management?
- Are buyers generally enthusiastic, cautious, or indifferent towards these technologies?

12. Additionally, what challenges or barriers do you believe buyers face when it comes to partnering with technology solution providers for (ESG) risk management?

Importance of ESG Factors

13. How important do buyers perceive Environmental, Social, and Governance factors to be in their decision-making processes?
- Are there specific ESG aspects that receive more attention than others?

Compliance with CSDDD

14. How aware and prepared are buyers regarding the EU's CSDDD?
- What steps are they taking to ensure compliance with its objectives?

Ending

15. Thank you for your participation and the valuable information you provided. Is there any other information you would like to add?

APPENDIX IV - INTERVIEW PROTOCOL TECHNOLOGY SOLUTION PROVIDERS

Interview Protocol – Technology Solution Provider

Technology Solution(s)

I am interested in various technology solutions that can assist in risk management in the field of PSM. I already investigated various solutions and advanced technologies, including the use of Industry 4.0 technologies.

1. Could you please provide an overview of technology solution(s) your organisation offers for risk management in the field of Purchasing and Supply Management (PSM)?

Industry 4.0 in the field of PSM refers, for instance, to the integration of digital technologies such as automation, data sharing and analytics to optimise (supply chain) processes and to improve decision-making. Technologies include, for instance, Artificial Intelligence and Blockchain.

2. Please elaborate on the use/focus on Industry 4.0 technologies in your technology solution(s).

I am also looking into the various stages of risk management. The four stages I used for my research include risk identification, assessment, management, and monitoring.

- The process of risk **identification** involves the recognition and understanding of potential uncertainties or sources of risks.
- Risk **assessment** involves the evaluation of the identified risk factors based on their probability and consequences and prioritising them.
- The **management** of risks includes strategies such as risk taking, transfer, elimination, minimisation, and detailed analysis to address and manage potential risks.
- Risk **monitoring** can be defined as the use of indicators to regularly evaluate the likelihood of, and possible changes within the occurrence of risks.

3. Please also specify and explain what risk management stages your solution(s) focus on – risk identification, assessment, management, and monitoring.

Current Focus on ESG Factors

I am also looking into the concept of ESG - Environmental, Social, and Governance – and its role in the field of PSM.

4. How does your organisation prioritise Environmental (E), Social (S), and Governance (G) (ESG) factors in the technology solutions you are offering for Purchasing and Supply Management and ESG risk management?
5. Can you please elaborate on the specific Environmental, Social, and Governance factors that are integrated into your technology solutions?

Compliance with Regulatory Requirements

6. How does/do your technology solution(s) support compliance with changing environmental and social regulations?

I am also interested in the new Corporate Sustainability due Diligence Directive (CSDDD), issued by the EU. The CSDDD requires organisations that fall within its scope to integrate due diligence into their corporate policies and supply chains to identify, prevent, and mitigate potential and actual adverse impacts on human rights and the environment.

7. To what extent does your technology solution(s) support compliance with the objectives of the CSDDD?
8. Are/will any features or functionalities (be) specifically designed to address the objectives CSDDD, focusing on Environmental (E), Social (S), and Governance (G) aspects? Please elaborate.

Expectations from PSM Experts

9. Based on your interactions with PSM experts/buyers, what do you think their expectations are regarding technology solutions for managing ESG risks in the field of Purchasing and Supply Management?
10. How do you ensure that your technology solution(s) meet(s) or exceed(s) these expectations?

Future Goals and Development

11. How do you envision the future of your (Industry 4.0) technological solution(s) for risk management in the field of Purchasing and Supply Management?
12. How do you envision the evolution of your (Industry 4.0) technology solution(s) to meet the changing needs and ESG challenges in the field of Purchasing and Supply Management? Please also provide a timeframe.

Ending

13. Thank you for your participation and the valuable information you provided. Is there any other information you would like to add?

APPENDIX V – DATA ACCOUNTING SHEET PSM EXPERTS/BUYERS

Data accounting sheet 1 - PSM experts/buyers

Questions		Topics	No Incorporation	Limited Incorporation	Moderate Incorporation	Strong Incorporation	Explanation
		Current Risk Management					
1	What strategies or approaches does your organisation employ to manage risks in the field of Purchasing and Supply Management?	General risk management					
2	Please provide insights into how risks are identified, assessed, managed and monitored within your organisation.	Identification					
		Assessment					
		Management					
		Monitoring					
		Current Focus on ESG Factors and Compliance					
3	Could you please specify the extent to which your organisation focuses on Environmental (E), Social (S), and Governance (G) (ESG) factors within its Purchasing and Supply Management (PSM) department?	ESG Focus					
3a	What environmental factors does your organisation address in PSM?	Measures to Avoid Adverse Impacts on Biological Diversity					
		Forest Protection and Anti-Deforestation					
		Soil Conservation and Prevention of Land Degradation					
		Greenhouse Gas Emissions Reduction					
		Marine Pollution Prevention					
		Trade in Endangered Species					
		Material and Resource Conservation					
		Chemical Control					
		Substances Depleting the Ozone Layer					
		Waste Reduction and Management					
3b	What social factors does your organisation address in PSM?	Labor and Human Rights					
		Child Labour and Protection					
		Forced Labour and Modern Slavery					
		Human Trafficking					
		Worker Rights and Fair Practices					
		Living Wages and Incomes					
		Indigenous Peoples' Rights					
3c	What governance factors does your organisation address in PSM?	Incentive Schemes					
4	To what extent does your organisation focus on compliance with the objectives of the CSDDD?						

		Technology Usage for Risk Management and ESG					
5	Which technologies or software solutions does your organisation currently utilise for overall risk management within Purchasing and Supply Management?	Risk Management					
6	Additionally, which specific technologies or software solutions are employed for ESG risk management in Purchasing and Supply Management?	ESG Risk Management					
		Expectations from Technology Solutions for ESG compliance					
7	What functionalities or capabilities do you think a technology solution should possess to effectively meet sustainability requirements, taking into account possible future regulatory frameworks?	Technology Solutions for Compliance					
8	Please also differentiate between the expectations for addressing Environmental, Social, and Governance aspects within the changing regulatory environment.	ESG Focus					
8a	Please elaborate on the environmental aspects	Measures to Avoid Adverse Impacts on Biological Diversity					
		Forest Protection and Anti-Deforestation					
		Soil Conservation and Prevention of Land Degradation					
		Greenhouse Gas Emissions Reduction					
		Marine Pollution Prevention					
		Trade in Endangered Species					
		Material and Resource Conservation					
		Chemical Control					
		Substances Depleting the Ozone Layer					
		Waste Reduction and Management					
8b	Please elaborate on the social aspects	Labor and Human Rights					
		Child Labour and Protection					
		Forced Labour and Modern Slavery					
		Human Trafficking					
		Worker Rights and Fair Practices					
		Living Wages and Incomes					
		Indigenous Peoples' Rights					
8c	Please elaborate on the governance aspects	Incentive Schemes					
		Future Expectations from Technology Solutions					
9	Looking ahead, what are your organisation's expectations regarding the role of Industry 4.0 technologies in addressing ESG risk management concerns in Purchasing and Supply Management?						
10	How do you anticipate these technologies evolving to meet future ESG compliance and risk management needs? Please also provide a timeframe.						

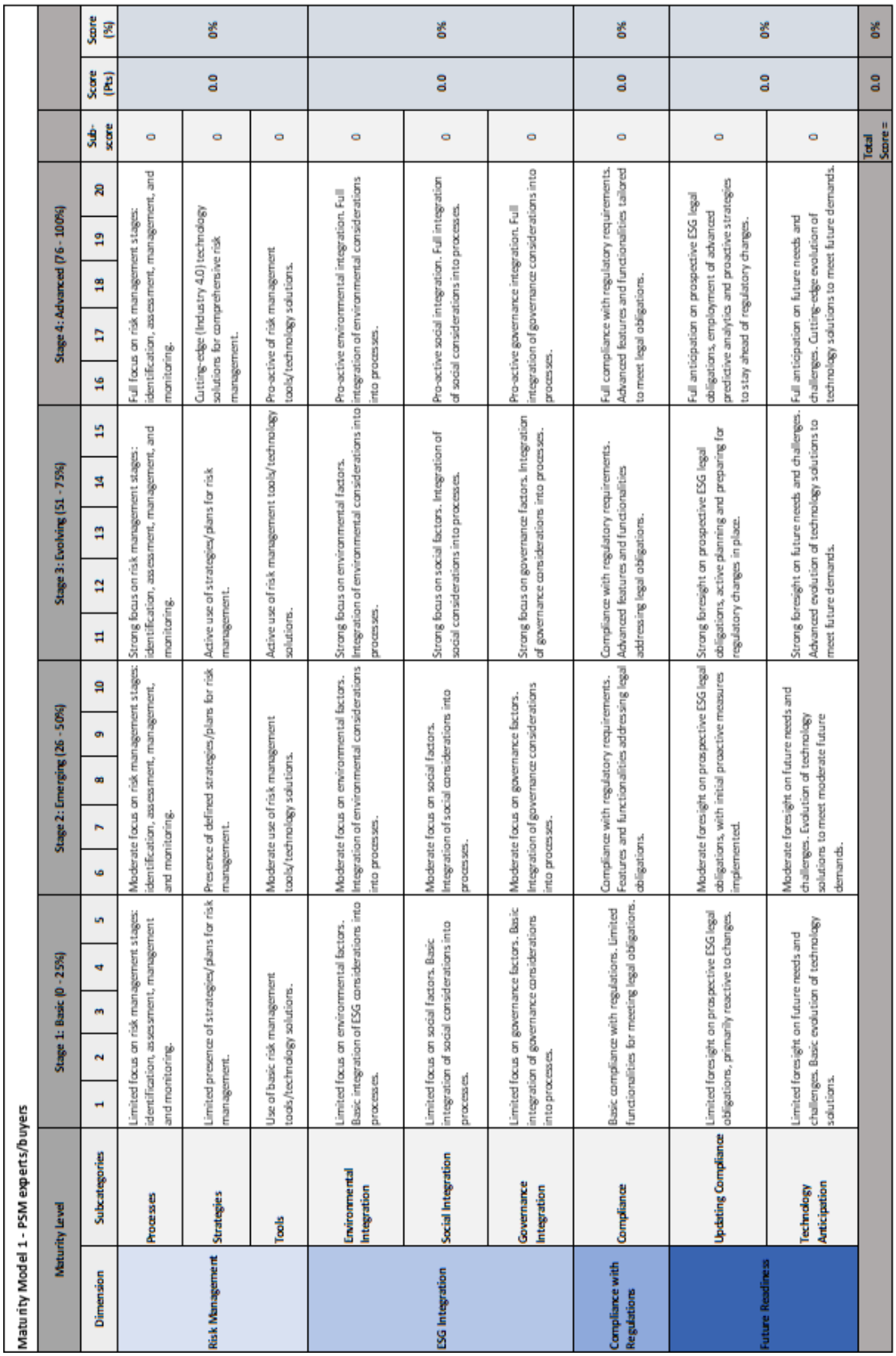
APPENDIX VI – DATA ACCOUNTING SHEET TECHNOLOGY SOLUTION PROVIDERS

Data accounting sheet 2 - Technology solution providers

Questions		Topics	No Incorporation	Limited Incorporation	Moderate Incorporation	Strong Incorporation	Explanation
		Technology Solution(s)					
1	Could you please provide an overview of technology solution(s) your organisation offers for risk management in the field of Purchasing and Supply Management (PSM)?	General risk management					
2	Please also elaborate on the use/focus on Industry 4.0 technologies in your technology solution(s).	Technology usage					
3	Please also specify and explain what risk management stages your solution(s) primarily focus on – risk identification, assessment, management, and monitoring.	Identification					
		Monitoring					
		Current Focus on ESG Factors					
4	How does your organisation prioritise Environmental (E), Social (S), and Governance (G) (ESG) factors in the technology solutions you are offering for Purchasing and Supply Management and ESG risk management?	ESG Focus					
5	Can you elaborate on the specific Environmental, Social, and Governance factors that are integrated into your technology solutions?	ESG Focus					
5a	What environmental factors does your organisation address in PSM? (e.g. carbon emissions, waste disposal)	Measures to Avoid Adverse Impacts on Biological Diversity					
		Forest Protection and Anti-Deforestation					
		Soil Conservation and Prevention of Land Degradation					
		Greenhouse Gas Emissions Reduction					
		Marine Pollution Prevention					
		Trade in Endangered Species					
		Material and Resource Conservation					
		Chemical Control					
		Substances Depleting the Ozone Layer					
		Waste Reduction and Management					
5b	How does your organisation address social factors in PSM? (e.g. labour rights, child labour, human trafficking)	Labor and Human Rights					
		Child Labour and Protection					
		Forced Labour and Modern Slavery					
		Human Trafficking					
		Worker Rights and Fair Practices					
		Living Wages and Incomes					
		Indigenous Peoples' Rights					
5c	What governance factors are emphasised in your organisation's PSM practices? (e.g. incentive schemes)	Incentive Schemes					

		Compliance with Regulatory Requirements					
6	How does/do your technology solution(s) support compliance with changing environmental and social regulations?	ESG Risk Management/Compliance					
7	To what extent does your technology solution(s) support compliance with the objectives of the CSDDD?	CSDDD regulatory support					
8	Are/will any features or functionalities (be) specifically designed to address the objectives CSDDD, focusing on Environmental (E), Social (S), and Governance (G) aspects?	ESG Focus					
8a	Please elaborate on the environmental aspects	Measures to Avoid Adverse Impacts on Biological Diversity					
		Forest Protection and Anti-Deforestation					
		Soil Conservation and Prevention of Land Degradation					
		Greenhouse Gas Emissions Reduction					
		Marine Pollution Prevention					
		Trade in Endangered Species					
		Material and Resource Conservation					
		Chemical Control					
		Substances Depleting the Ozone Layer					
		Waste Reduction and Management					
8b	Please elaborate on the social aspects	Labor and Human Rights					
		Child Labour and Protection					
		Forced Labour and Modern Slavery					
		Human Trafficking					
		Worker Rights and Fair Practices					
		Living Wages and Incomes					
		Indigenous Peoples' Rights					
8c	Please elaborate on the governance aspects	Incentive Schemes					
		Expectations from PSM Experts					
9	Based on your interactions with PSM experts, what are their expectations regarding technology solutions for managing ESG risks in the field of Purchasing and Supply Management?	Expectations					
10	How do you ensure that your technology solution(s) meet(s) or exceed(s) these expectations?	Meeting expectations					
		Future Goals and Development					
11	How do you envision the future of your (Industry 4.0) technological solution(s) for risk management in the field of Purchasing and Supply Management?	Future of technological solutions					
12	How do you envision the evolution of your (Industry 4.0) technology solution(s) to meet the changing needs and ESG challenges in the field of Purchasing and Supply Management? Please also provide a timeframe.	Future of technological solutions regarding ESG challenges					

APPENDIX VII – MATURITY MODEL PSM EXPERTS/BUYERS



Maturity Model 1 - PSM experts/buyers

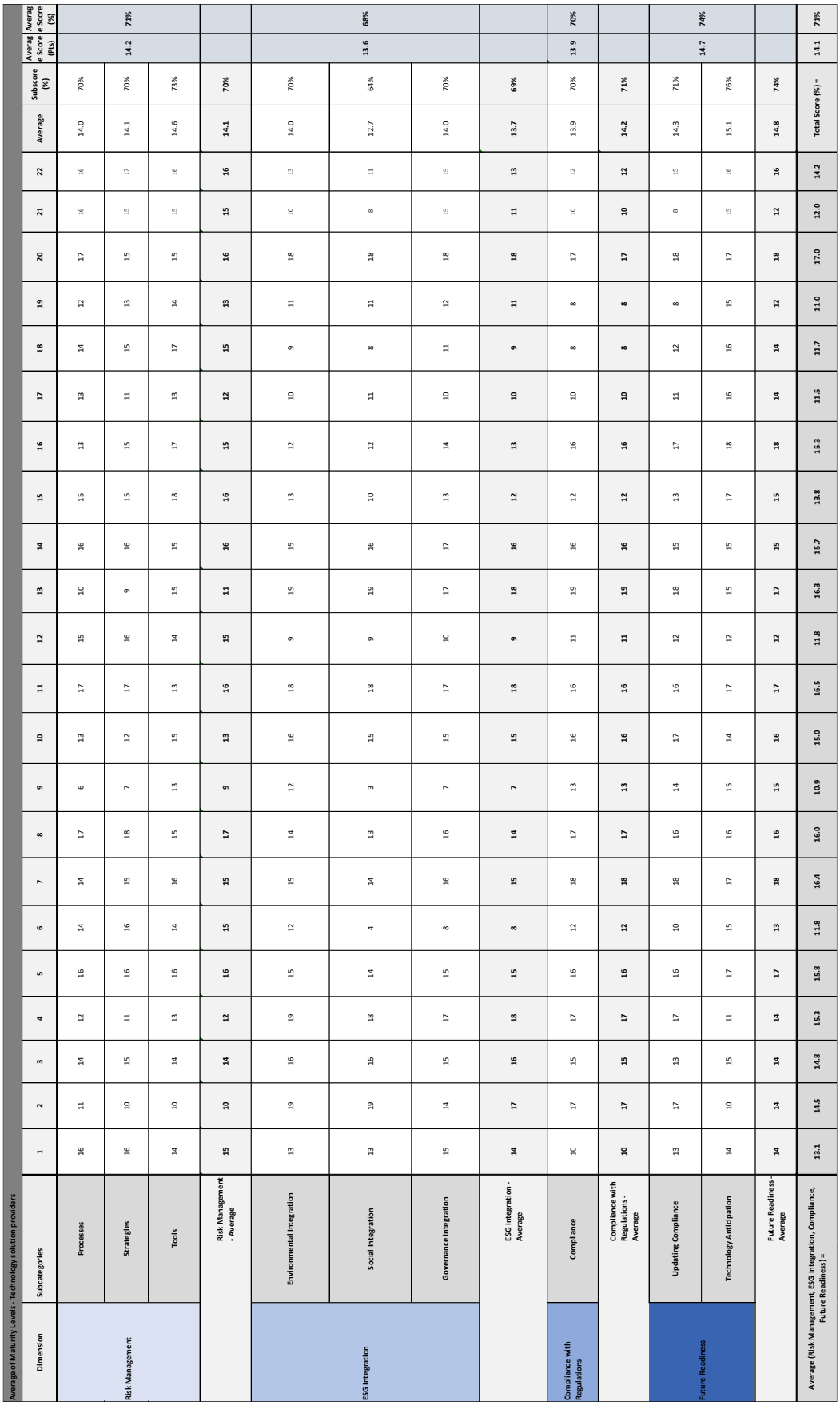
Maturity Level		Stage 1: Basic (0 - 25%)					Stage 2: Emerging (26 - 50%)					Stage 3: Evolving (51 - 75%)					Stage 4: Advanced (76 - 100%)							
Dimension	Subcategories	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Sub-score	Score (Pts)	Score (%)
Risk Management	Processes	Limited focus on risk management stages: identification, assessment, management, and monitoring.					Moderate focus on risk management stages: identification, assessment, management, and monitoring.					Strong focus on risk management stages: identification, assessment, management, and monitoring.					Full focus on risk management stages: identification, assessment, management, and monitoring.					0		
	Strategies	Limited presence of strategies/plans for risk management.					Presence of defined strategies/plans for risk management.					Active use of strategies/plans for risk management.					Cutting-edge (Industry 4.0) technology solutions for comprehensive risk management.					0	0.0	0%
	Tools	Use of basic risk management tools/technology solutions.					Moderate use of risk management tools/technology solutions.					Active use of risk management tools/technology solutions.					Pro-active of risk management tools/technology solutions.					0		
ESG Integration	Environmental Integration	Limited focus on environmental factors. Basic integration of ESG considerations into processes.					Moderate focus on environmental factors. Integration of environmental considerations into processes.					Strong focus on environmental factors. Integration of environmental considerations into processes.					Pro-active environmental integration. Full integration of environmental considerations into processes.					0		
	Social Integration	Limited focus on social factors. Basic integration of social considerations into processes.					Moderate focus on social factors. Integration of social considerations into processes.					Strong focus on social factors. Integration of social considerations into processes.					Pro-active social integration. Full integration of social considerations into processes.					0	0.0	0%
	Governance Integration	Limited focus on governance factors. Basic integration of governance considerations into processes.					Moderate focus on governance factors. Integration of governance considerations into processes.					Strong focus on governance factors. Integration of governance considerations into processes.					Pro-active governance integration. Full integration of governance considerations into processes.					0		
Compliance with Regulations	Compliance	Basic compliance with regulations. Limited functionalities for meeting legal obligations.					Compliance with regulatory requirements. Features and functionalities addressing legal obligations.					Compliance with regulatory requirements. Advanced features and functionalities addressing legal obligations.					Full compliance with regulatory requirements. Advanced features and functionalities tailored to meet legal obligations.					0	0.0	0%
Future Readiness	Updating Compliance	Limited foresight on prospective ESG legal obligations, primarily reactive to changes.					Moderate foresight on prospective ESG legal obligations, with initial proactive measures implemented.					Strong foresight on prospective ESG legal obligations, active planning and preparing for regulatory changes in place.					Full anticipation on prospective ESG legal obligations, employment of advanced predictive analytics and proactive strategies to stay ahead of regulatory changes.					0	0.0	0%
	Technology Anticipation	Limited foresight on future needs and challenges. Basic evolution of technology solutions.					Moderate foresight on future needs and challenges. Evolution of technology solutions to meet moderate future demands.					Strong foresight on future needs and challenges. Advanced evolution of technology solutions to meet future demands.					Full anticipation on future needs and challenges. Cutting-edge evolution of technology solutions to meet future demands.					0		
																						Total Score =	0.0	0%

APPENDIX VIII – MATURITY MODEL TECHNOLOGY SOLUTION PROVIDERS

Maturity Model 2 - Technology solution providers

Maturity Level		Stage 1: Basic (0 - 25%)	Stage 2: Emerging (26 - 50%)	Stage 3: Evolving (51 - 75%)	Stage 4: Advanced (76 - 100%)			
Dimension	**Subcategories**	**1 2 3 4 5**	**6 7 8 9 10**	**11 12 13 14 15**	**16 17 18 19 20**	**Sub-score**	**Score (Pts)**	**Score (%)**
Risk Management	**Processes**	Limited focus on risk management stages: identification, assessment, management and monitoring.	Moderate focus on risk management stages: identification, assessment, management, and monitoring.	Strong focus on risk management stages: identification, assessment, management, and monitoring.	Full focus on risk management stages: identification, assessment, management, and monitoring.	0	0.0	0%
	Strategies	Limited presence of strategies/plans for risk management.	Presence of defined strategies/plans for risk management.	Active use of strategies/plans for risk management.	Cutting-edge use of strategies/plans for risk management.	0		
	Tools	Basic technology solutions with limited functionalities for risk management.	Moderate technology solutions with defined functionalities for risk management.	Advanced technology solutions for comprehensive risk management.	Cutting-edge (Industry 4.0) technology solutions for comprehensive risk management.	0		
ESG Integration	**Environmental Integration**	Limited focus on environmental factors. Basic integration of ESG considerations into technologies/technology solutions.	Moderate focus on environmental factors. Integration of environmental considerations into technologies/technology solutions.	Strong focus on environmental factors. Integration of environmental considerations into technologies/technology solutions.	Pro-active environmental integration. Full integration of environmental considerations into technologies/technology solutions.	0	0.0	0%
	Social Integration	Limited focus on social factors. Basic integration of social considerations into technologies/technology solutions.	Moderate focus on social factors. Integration of social considerations into technologies/technology solutions.	Strong focus on social factors. Integration of social considerations into technologies/technology solutions.	Pro-active social integration. Full integration of social considerations into technologies/technology solutions.	0		
	Governance Integration	Limited focus on governance factors. Basic integration of governance considerations into technologies/technology solutions.	Moderate focus on governance factors. Integration of governance considerations into technologies/technology solutions.	Strong focus on governance factors. Integration of governance considerations into technologies/technology solutions.	Pro-active governance integration. Full integration of governance considerations into technologies/technology solutions.	0		
Compliance with Regulations	**Compliance**	Limited focus on compliance with regulations. Limited functionalities for meeting legal obligations.	Compliance with regulatory requirements. Features and functionalities addressing legal obligations.	Compliance with regulatory requirements. Advanced features and functionalities addressing legal obligations.	Full compliance with regulatory requirements. Advanced features and functionalities tailored to meet legal obligations.	0	0.0	0%
Future Readiness	**Updating Compliance**	Limited foresight on prospective ESG legal obligations.	Moderate foresight on prospective ESG legal obligations.	Strong foresight on prospective ESG legal obligations.	Full anticipation on prospective ESG legal obligations.	0	0.0	0%
	Technology Anticipation	Limited foresight on future needs and challenges. Basic evolution of technology solutions.	Moderate foresight on future needs and challenges. Evolution of technology solutions to meet moderate future demands.	Strong foresight on future needs and challenges. Advanced evolution of technology solutions to meet future demands.	Full anticipation on future needs and challenges. Cutting-edge evolution of technology solutions to meet future demands.	0		
						Total Score =	**0.0**	**0%**

APPENDIX IX – RESULTS MATURITY MODEL TECHNOLOGY SOLUTION PROVIDERS



Average of Maturity Levels - Technology solution providers																														
Dimension	Subcategories	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Average	Subscore (%)	Average Score (Pts)	Average Score (%)			
Risk Management	Processes	16	11	14	12	16	14	14	17	6	13	17	15	10	16	15	13	13	14	12	17	16	16	14.0	70%	14.2	71%			
	Strategies	16	10	15	11	16	16	15	18	7	12	17	16	9	15	15	15	11	15	13	15	15	17	14.1	70%					
	Tools	14	10	14	13	16	14	16	15	13	15	13	14	15	18	18	17	13	17	14	15	15	16	14.6	73%					
Risk Management - Average		15	10	14	12	16	15	15	17	9	13	16	15	11	16	16	15	12	15	13	16	15	16	14.1	70%					
ESG Integration	Environmental Integration	13	19	16	19	15	12	15	14	12	16	18	9	19	15	13	12	10	9	11	18	10	13	14.0	70%	13.6	68%			
	Social Integration	13	19	16	18	14	4	14	13	3	15	18	9	19	16	10	12	11	8	11	18	8	11	12.7	64%					
	Governance Integration	15	14	15	17	15	8	16	16	7	15	17	10	17	17	13	14	10	11	12	18	15	15	14.0	70%					
ESG Integration - Average		14	17	16	18	15	8	15	14	7	15	18	9	18	16	12	13	10	9	11	18	11	13	13.7	69%					
Compliance with Regulations	Compliance	10	17	15	17	16	12	18	17	13	16	16	11	19	16	12	16	10	8	8	17	10	12	13.9	70%	13.9	70%			
Compliance with Regulations - Average		10	17	15	17	16	12	18	17	13	16	16	11	19	16	12	16	10	8	8	17	10	12	14.2	71%					
Future Readiness	Updating Compliance	13	17	13	17	16	10	18	16	14	17	16	12	18	15	13	17	11	12	8	18	8	15	14.3	71%	14.7	74%			
	Technology Anticipation	14	10	15	11	17	15	17	16	15	14	17	12	15	17	15	18	14	16	15	17	15	16	15.1	76%					
Future Readiness - Average		14	14	14	14	17	13	18	16	15	16	17	12	17	15	13	18	14	14	12	18	12	16	14.8	74%					
Average (Risk Management, ESG Integration, Compliance, Future Readiness) =		13.1	14.5	14.8	15.3	15.8	11.8	16.4	16.0	10.9	15.0	16.5	11.8	16.3	15.7	13.8	15.3	11.5	11.7	11.0	17.0	12.0	14.2	Total Score (%) =		14.1	71%			