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SELECTING SUSTAINABILITY KEY PERFORMANCE INDICATORS FOR SMART LOGISTICS ASSESSMENT

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Abstract: The application of smart technologies and applications is becoming increasingly common in the logistics processes of companies and supply chains. However, standard logistics indicators are still used to evaluate their performance, which contradicts the sustainable development strategy of many industrial enterprises and their supply chains. Thus, the article aims to design a methodology for selecting sustainability key performance indicators (SKPIs) suitable for assessing smart logistics and its technologies and applications. The research relies on cluster analysis of the SKPIs recommended in the relevant literature, frequency analysis of indicators used in practice and their comparison. The cluster analysis showed that the primary attention in the references is given to sustainability's economic and environmental dimensions. Most frequently, the authors highlighted the importance of the following indicators: production-related costs and investments, planning performance and quality, customer satisfaction, energy efficiency, waste intensity and treatment, emissions, and resource efficiency. On the contrary, the frequency analysis corroborated that leading industrial enterprises paid more-or-less balanced attention to all areas of sustainability, but at the company level. The article's primary result constitutes a methodology comprising six steps, respecting the results of the analyses carried out: (1) Sustainability objectives definition; (2) Establishing SKPIs cluster pool; (3) Definition of criteria for selecting SKPIs clusters; (4) Selection of SKPIs clusters; (5) Definition of SKPIs and their parameters; and (6) Development of SKPIs hierarchical structure.

1 Introduction

One of the key trends in contemporary logistics is the introduction of new technologies to improve the logistics process efficiency. These technologies have come to be known as smart technologies or technologies of the fourth industrial revolution (Industry 4.0). Thus, a new concept known as smart logistics or Logistics 4.0 has emerged. However, in practice, the implementation and operation of smart logistics technologies and applications are evaluated only in terms of standard logistics performance indicators. The given indicators focus on evaluating logistics processes' productivity, economics, quality, and lead times. However, that does not correspond to the current requirements for the sustainability of the business and, thus, logistics. Yet, sustainability is nowadays considered one of the primary strategies for increasing the value of businesses, as well as entire supply chains [1].

Sustainability is a long-term approach to business [2]. The sustainability strategy relies on balancing the three pillars of sustainability (triple bottom line approach): economic, environmental, and social [3,4]. If smart logistics technologies and applications are to deliver sustainable value, their performance must be measured by a system of sustainable key performance indicators (SKPIs). Although the scientific and professional literature describes an extensive set of various SKPIs, their selection for evaluating smart logistics, their technologies and applications still constitute a significant research gap. The literature review (see Chapter 2.2) proved that there are very few studies on SKPs for smart logistics. Similarly, there are only some studies on the methodology used to select the most suitable SKPIs, none addressing smart logistics.

Therefore, the article aims to propose a methodology for selecting SKPIs suitable for assessing the sustainability performance of smart logistics and its technologies and applications. To achieve the stated objective, the following two research questions were defined:

1. Which SKPIs can be applied to assess the sustainability performance of smart logistics and its technologies and applications?
2. How can the appropriate SKPIs be selected to assess the sustainability performance of smart logistics and its technologies and applications?

The following approaches were used to address the research questions and achieve the research objective:

1. Cluster analysis of SKPIs obtained from explanatory literature review on SKIPs for smart logistics (see Chapter 3.1). The aim was to identify the SKIPs recommended by the scientific community for evaluating smart logistics and its technologies and perform their classification and frequency analysis.
2. Frequency analysis concerning the employment of SKPIs recommended by the United Nations Conference on Trade and Development (UNCTAD) in practice (see Chapter 3.2). UNCTAD has proposed a set of SKPIs suitable for managing sustainability at the company level. This analysis aimed to identify the groups of SKPIs that are most frequently used in business practice, as the implementation of smart logistics technologies and applications should contribute to their improvement.
3. A comparison of the performed analysis results (see Chapter 3.3) aiming to determine similarities, differences, and interrelationships between the identified SKPIs clusters.
4. Synthesis of acquired knowledge and proposal of the methodology for selecting SKPIs suitable for assessing the sustainability of smart logistics (see Chapter 4) to develop a procedure for evaluating the sustainable performance of smart logistics technologies and applications at different managerial levels of a company or supply chain.

The article presents a new, previously undeveloped methodology for assessing the sustainability performance of smart logistics and its technologies and applications. The innovative elements of the proposed methodology include in particular:

- Comprehensive approach. The methodology can be applied independently at different management levels: supply chain, enterprise, logistics process and smart logistics technology and application.
- Combination of standardised and tailor-made approaches. On the one hand, the methodology outlines a standardised set of SKPIs for assessing s company or supply chain. On the other hand, it allows comparing the implementation of smart technologies and applications within various logistics processes of a company or supply chain while respecting its specific needs.
- Feedback-based SKPIs selection process. The methodology has been developed as an iterative process enabling backtracking to previously adopted and re-evaluated procedures.
- Multi-source based SKPIs selection process. The methodology offers a combination of clearly defined sources for establishing the SKPIs cluster pool.

The study results are intended for managers requiring measuring, evaluating and improving the sustainability performance of smart logistics and its technologies and applications at different levels of management: supply chain, company, logistics department or processes.

The remaining parts are organised as follows. Chapter 2 reviews the literature on smart logistics and sustainability key performance indicators; Chapter 3 presents cluster analysis of SKPIs obtained from the relevant literature review, frequency analysis concerning the application of SKPIs recommended by UNCTAD in practice and their comparative analysis; Chapter 4 describes and discusses the primary article result, i. e., the proposed methodology for selecting SKPIs for smart logistics sustainability assessment; and, finally, Chapter 5 summarises the results.

2 Literature review

Considering the article's objective to be fulfilled, the relevant literature on smart logistics and sustainability key performance indicators was reviewed.

2.1 Smart logistics

In the complex logistics and supply chain management environment, the widespread application of information technologies (IT) has been inevitable in recent decades. The boundary between the digital world and the physical world, often referred to as Operational Technology (OT), is becoming increasingly blurred due to the growing interest in the practice and research on digitalisation in the industry (i. e., "Industry 4.0") on the one side, and the decreasing costs of computing power on the other [5]. Non-traditional approaches, such as logistics assets or load carriers, are becoming network-capable, shaping the concept of the Internet of Things (IoT) and the principle of interconnection. Augmenting these "things" with sensors and actuators allows sensing and manipulating the physical world and creating Cyber-Physical Systems that follow the principles of autonomation and decentralised control [6].

Fulfilling these fundamental principles of Industry 4.0 [7] in Smart logistics applications ensures an impact on the visibility, reliability, and agility of logistics processes, ultimately affecting the logistics objectives [8]. Numerous potential positive effects are attributed to the application of these technologies and technological concepts in logistics; for example, enhanced process stability [9], reduced production delays [10], transportation costs [11], stock levels [12], and even reduction of environmental impacts, such as Greenhouse Gas emissions [11]. In sum, the perceived potentials of digitalisation in logistics can be expected to affect financial, environmental, and social indicators, which still need to be scientifically evaluated [13].

2.2 Sustainability key performance indicators

There are many systems and models for assessing logistics and supply chain performance. A review of the available topic-related literature is provided, for example, by Oubrahim et al. [14]. Hierarchical- and dimension-based performance appraisal systems are suitable for assessing sustainable performance at different levels of managerial decision-making. To link a company or supply chain strategy with actual performance, it is necessary to develop objectives and define an applicable set of key performance indicators (KPIs) describing the company or supply chain performance [15]. KPIs represent a set of metrics focused on the types of company or supply chain performance that are most relevant to the effectiveness of the current and future company or supply chain design [16]. KPIs provide quantitative or qualitative feedback that should translate into the results of a company or supply chain strategy [17]. SKPIs measure progress towards achieving a sustainable company or supply chain strategy in terms of environmental, social and economic impacts. Gebhardt et al. [18] demonstrated that implementing SKPIs in the company or supply chain in-house management system improves sustainability performance. According to Olabi et al. [19], indicators reflecting the sustainable development goals defined by the United Nations should be chosen to evaluate technological improvements.

SKPIs should be defined at all decision-making levels, such as supply chain, company, department or process [20]. A considerable number of studies recommend suitable SKPIs for these decision-making levels that are related to logistics processes. For example, Neri et al. [21] proposed a balanced set of 33 SKPIs (Triple bottom line) to measure the sustainability performance of industrial supply chains based on the balanced scorecard approach. Contini and Peruzzini [22] provided a comprehensive overview of company SKPIs based on a systematic literature review. They identified a set of 117 SKPIs that allow measuring the general corporate sustainability performance according to the triple bottom line approach in manufacturing companies. On the contrary, Hristov and Chirico [23] recommended the 14 most appropriate SKPIs for the company level based on a literature review and a survey conducted among Italian managers. Similarly, Swarnakar et al. [24] proposed a list of 18 SKPIs to assess a manufacturing company's sustainability performance. Bouchery et al. [25] designed a standard set of SKPIs for distribution processes based on 17 transportation and warehousing SKPIs. Torabizadeh et al. [26] put forward a list of 33 SKPIs for a sustainable warehouse management system. Kursini et al. [27] identified a list of 30 SKPIs for a sustainable warehouse in the leather manufacturing industry.

The literature review has demonstrated that very few studies focused on SKPs for smart logistics [28-32]. Their detailed analysis is included in Chapter 3.1. Similarly, only some studies address the selection methodology of the most suitable SKPIs, none focusing on smart logistics. Tyndus and Fernando [33] developed a reference model for implementing SKPIs at the supply chain level. Keeble et al. [34] proposed models for determining SKPIs at the company and project levels. Kibira et al. [35] designed a procedure for manufacturers to select KPIs for measuring, monitoring, and improving the environmental aspects of manufacturing processes.

3 Data analysis

3.1 Cluster analysis of SKPIs obtained from the relevant literature review

A review of the relevant literature on SKIPs for smart logistics was conducted to generate a list of possible SKPIs recommended by the scientific community. The review involved using a combination of the keywords listed in the upper part of Table 1 to formulate a search query for the SCOPUS database. The search string was further extended to ensure high-quality results so that only journal articles ("ar"), conference proceedings ("cp") and book chapters ("bc"), as well as in thematically relevant fields of research, were included. The search results were further reviewed, and articles focusing on sustainability and digitalisation were selected; on the other hand, papers solely focusing on applying the Global Reporting Initiative Standards were excluded.

SCOPUS constituted the only database source due to its high relevance for scientific publications in industrial engineering and management sciences [36]. Moreover, other research results have suggested that the information differs only minimally when extending the search to other databases, such as the Web of Science [37].

Considering the high number of SKPIs identified during the initial manual database screening, the syntactic and semantic aggregation to clusters was necessary. The aggregation was accomplished in several steps, including automated clustering, followed by several manual loops and discussion rounds on the clusters.

Table 1 SCOPUS-based search string formulation

Search string		Keyword I AND	Keyword II AND	Keyword III AND	Keyword III
TITLE-ABS-KEY	**Keyword**	sustainability	indicator	Industr* 4.0	logistic*
	Synonyms	sustainable	reporting	digitali*ation	manufacturing
			index	digiti*ation	production
				smart logistics	
LIMIT-TO	**Options**	**LIMIT**	**SUBJAREA**		
		DOCTYPE, “ar”	SUBJAREA , “ECON”		
		DOCTYPE, “cp”	SUBJAREA , “BUSI”		
		DOCTYPE, “ch”	SUBJAREA , “ENGI”		

Subsequently, the identified papers were analysed, and all SKPIs were extracted and gathered in a standard Excel spreadsheet to be used as a database. If the article contained multiple mentions, appropriate references were also made in the database. By doing so, the relevance of the SKPI was taken into account. A summary of the literature analysed is presented in Table 2.

Table 2 List of identified references

Reference	**Methodology**	**Focus**
Kayikci, 2018	Delphi method (4 FMCG, 2 Transport), literature review and expert opinions	FMCG and Transport
Felsberger and Reiner, 2020	KPI selection: focus group interviews	How to measure the I4.0 impact
Takhar and Liyanage, 2020	Research and literature review, literature review on reporting requirements	Sustainability and circular economy data reporting using I4.0 technologies
Gunduz *et al.*, 2021	Literature review and QFD-methods (Quality Function Deployment)	Assessing the maturity level for supply chain smartness and sustainability
Nantee and Sureeyatanapas, 2021	Expert interviews, literature review on sustainability indicators	Logistics 4.0 impact on corporate sustainability performance

For the automatic syntactic clustering in the first step, the SKPI list was migrated from Excel to the PostgreSQL database. KPIs similarity analysis was performed using the *word_similarity(text, text)* function, which returns “a number that indicates the greatest similarity between the set of trigrams in the first string and any continuous extent of an ordered set of trigrams in the second string” [38]. The result is an $n \times n$ matrix filled with similarity values $s_{i,j}$ between $SKPI_i$ and $SKPI_j$ $(0 \leq i, j < n)$ for all SKPIs. The higher $s_{i,j}$ is, the higher the syntactic similarity of the two words on indices i and j, defined by the trigram matching method. Consecutively, the matrix was uploaded into Python via a .csv file and used to cluster the SKPIs with the *AgglomerativeClustering* class provided by the scikit-learn project [39]. The code applied for the clustering can be found online [40].

This way, SKPIs with the same or similar wording, i. e., syntactically similar SKPIs, were clustered. Subsequently, manual clustering was performed for semantic analysis, and new clusters were introduced to link individual SKPIs in a thematic context. After adapting the database to use only quantitatively measurable SKPIs, the research team evaluated the clusters in several discussion rounds so that they could have been to one of the commonly applied sustainability pillars – economic, environmental, and social. Table 3 displays the final clusters, their distribution to the three pillars, and the frequency analysis. The clusters are ranked in descending order of frequency of their occurrence in sustainability pillars.

Table 3 Cluster analysis outputs

Sustainability		Occurrence in literature sources					∑	
Area	**SKPI cluster**	[28]	[29]	[30]	[31]	[32]	**pcs**	**%**
Economic	Production-related costs and investments	1	1	1	1	1	5	100
	Performance and quality of planning	1	1	1	1	1	5	100
	Customer satisfaction	1	1	0	1	1	4	80
	Profit and economic success	0	1	0	1	1	3	60
	Product quality	0	1	0	0	1	2	40
	Sustainable costs and investments	0	0	1	0	0	1	20
	Business ethics	0	0	0	1	0	1	20
	Marketing	0	1	0	0	0	1	20
	System reliability	0	1	0	0	0	1	20
Environmental	Energy efficiency	1	1	1	1	1	5	100
	Waste intensity and treatment	1	1	1	1	1	5	100
	Emissions	1	1	0	1	1	4	80
	Resource efficiency	1	1	0	1	1	4	80
	Water	0	0	1	0	0	1	20
	Green product	0	0	1	0	0	1	20
	Land use	1	0	0	0	0	1	20
Social	Occupational health and safety	1	1	0	1	0	3	60
	Diversity and equal opportunities	0	1	1	0	0	2	40
	Local communities	0	0	1	0	0	1	20
	Employment	0	1	0	0	0	1	20

3.2 Frequency analysis of the use of the UNCTAD-recommended SKPIs in practice

This approach of identifying SKPIs suitable for assessing the sustainability of smart logistics and its technologies and applications was based on the Guidance on Core Indicators for Entity Reporting on Contribution towards Implementation of the Sustainability Development Goals [41]. The Guidance was developed by United Nations Conference on Trade and Development (UNCTAD) and designed to assist business entities in providing baseline information on SKPIs consistently and comparably to meet the common needs of different stakeholders of the SDG agenda.

The Guidance classifies SKPIs into four main areas:

1. Economic – four SKPIs clusters and eight specific SKPIs,
2. Environmental – five clusters and eleven SKPIs,
3. Social – four clusters and seven SKPIs,
4. Institutional – two clusters and seven SKPIs.

This classification has been transformed into three standard sustainability pillars. The transformation relies on merging the economic and institutional clusters into the economic pillar.

The content analysis of sustainability reports of leading European industrial companies was performed to assess the preferences of SKPI clusters in corporate practice. A list of the 20 largest European companies by 2020 revenues was used to select the industrial entities. The list was drawn from Fortune 500 ranking database [42]. The following criteria were applied to refine the list of companies:

1. Industrial focus,
2. Existing sustainability report,
3. Existing comprehensive SKPIs system.

The final research sample included 11 industrial companies (see Table 4). SKPIs differ in terminology and measures across industrial enterprises. Thus, the substantive content of the reported SKPIs was essential for their assignment to the UNCTAD classification. The frequency analysis result is presented in Table 5, showing the clusters in descending order according to their occurrence frequency in the sustainability pillars. The environmental pillar, a core component of all the sustainability reports reviewed, displays the most consistent results. The frequency analysis of economic KPIs is influenced by companies referring to standard financial statements (not included in sustainability reports) while reporting.

Table 4 Research sample

No.	Company (Country)	Revenue in 2020 (in milliard USD)	Industry	Source
1.	Royal Dutch Shell (Netherlands)	352.11	Oil and gas	[43]
2.	Volkswagen (Germany)	282.76	Automotive	[44]
3.	Glencore (Switzerland)	215.11	Natural resources	[45]
4.	Daimler AG (Germany)	193.35	Automotive	[46]
5.	Total (France)	176.25	Oil and gas	[47]
6.	Gazprom (Russia)	118.01	Oil and gas	[48]
7.	BMW Group (Germany)	116.64	Automotive	[49]
8.	Lukoil (Russia)	114.62	Oil and gas	[50]
9.	Siemens (Germany)	97.94	Technology	[51]
10.	Nestle (Switzerland)	92.11	Food and beverage	[52]
11.	Enel Groupe (Italy)	89.91	Energy	[53]

Table 5 Frequency analysis of the UNCTAD-recommended SKPIs clusters

Sustainability		Occurrence in sustainability reports											∑	
Area	**KPI cluster**	Shell	VW	Glencore	Daimler	Total	Gazprom	BMW	Lukoil	Siemens	Nestle	Enel	**pcs**	**%**
Economic	Revenue and/or (net) value added	1	0	1	1	1	1	1	1	1	1	1	10	90,9
	New investment/expenditures	1	1	1	1	0	1	1	1	1	0	1	9	81,8
	Corporate governance disclosure	1	0	1	1	1	1	1	1	1	0	1	9	81,8
	Payments to the government	1	0	1	1	0	1	1	1	0	0	1	7	63,6
	Local supplier/purchasing programmes	1	0	1	0	0	1	0	0	0	0	1	4	36,4
	Anti-corruption practices	0	0	1	0	0	1	0	0	0	0	0	2	18,2
Environme	Sustainable use of water	1	1	1	1	1	1	1	1	1	1	1	11	100
	Waste management	1	1	1	1	1	1	1	1	1	1	1	11	100
	Greenhouse gas emissions	1	1	1	1	1	1	1	1	1	1	1	11	100
	Ozone-depleting substances	1	1	1	1	1	1	1	1	1	1	1	11	100
	Energy consumption	1	0	0	0	0	1	0	0	1	1	1	5	45,5
Social	Gender equality	1	1	0	1	1	1	1	1	1	1	1	10	90,9
	Human capital	1	1	1	0	1	1	1	1	1	1	1	10	90,9
	Employee health and safety	1	1	1	1	1	1	1	1	0	0	1	9	81,8
	Coverage by collective agreements	0	0	1	0	1	1	1	1	0	0	0	5	45,5

3.3 Comparative analysis of the results obtained

Having identified two sets of SKPIs clusters, the next step involved examining the relationships (differences and similarities) in the obtained sets – the set of SKPIs clusters identified in the literature, hereinafter referred to as Literature set, and the set of SKPIs defined by UNCTAD (UNCTAD, 2019), referred to as UNCTAD set.

The clusters identified in the Literature set were matched with those defined in the UNCTAD set as part of the comparison of the two sets. The matching was intended to identify the clusters missing in the newly defined Literature set compared to the generally accepted UNCTAD set and vice versa. The final matching is presented in Figure 1.

The two sets reveal only a few differences, suggesting, on the one hand, a shared comprehension of the SKPIs in the literature and practice. However, on the other hand, the results reveal a lack of focus in the generic SKPIs sets, mainly the focus on the impact of digitalisation on sustainability [54,55]. The key differences can be summarised in two topics, addressed in more detail in the Literature set – production-related issues and the impact of digitisation. Thus, the newly defined set proposes SKPIs relevant to operational processes in industrial companies, such as the introduction of “system reliability”, “process stability”, “throughput”, as well as “resource efficiency”, allowing a more accurate assessment of production processes and indicating possible effects of specific improvement measures. Furthermore, the literature review has identified SKPIs with a high probability of being influenced by digitisation initiatives, such as “performance and quality of planning” and “customer satisfaction”; they constitute crucial factors for adopting smart logistics concepts.

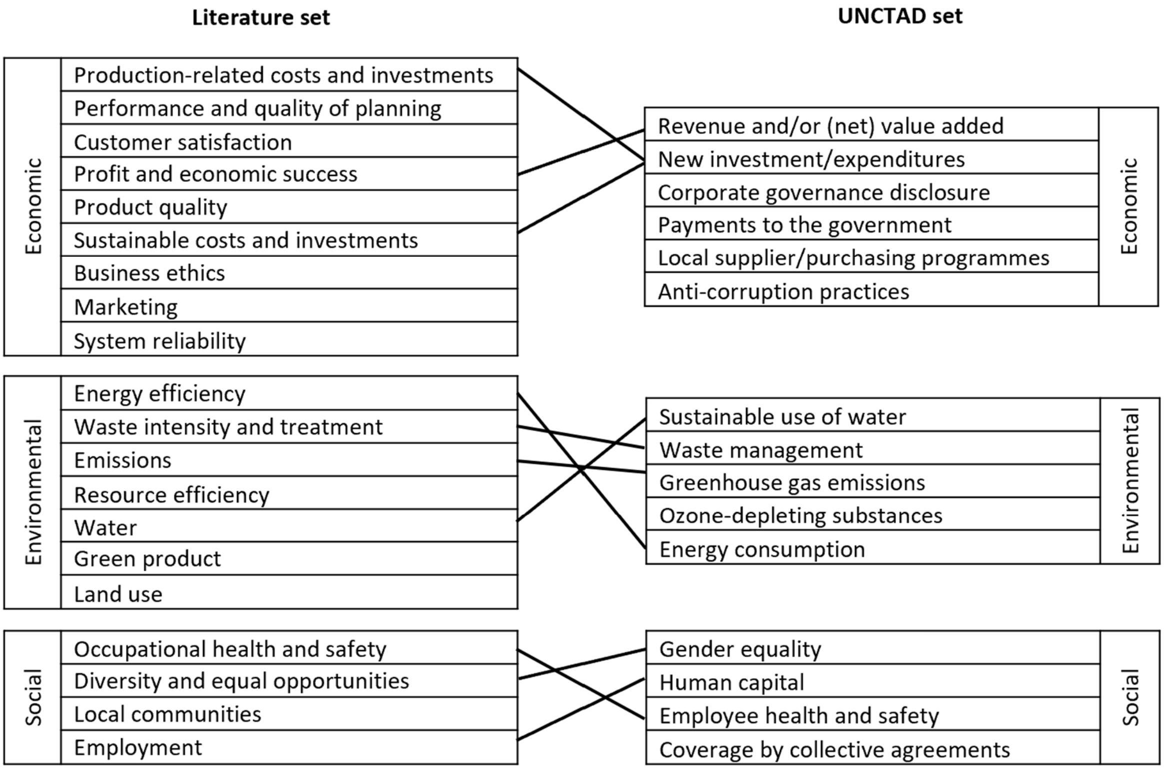

Figure 1 Matching the clusters from the literature to clusters from UNCTAD

4 Result and discussion

This chapter describes and discusses the main result of the article, namely the new SKPIs selection methodology for assessing the sustainability of smart logistics.

The professional community has not reached a consensus on whether to propose a global standardised set of SKPIs allowing comparisons between evaluated entities or processes or a case-by-case set of SKPIs tailored to a specific entity or process [25]. The proposed methodology attempts to combine both approaches and exploit their advantages. We propose developing a standardised set of SKPIs specific to the company or supply chain being evaluated. Although such an approach does not allow benchmarking with other companies or supply chains, it enables comparisons between the implementation of smart technologies and applications within various logistics processes of a company or supply chain while respecting its specific needs. If certain standard indicators are not relevant for particular smart technologies or applications, they are not included in the assessment.

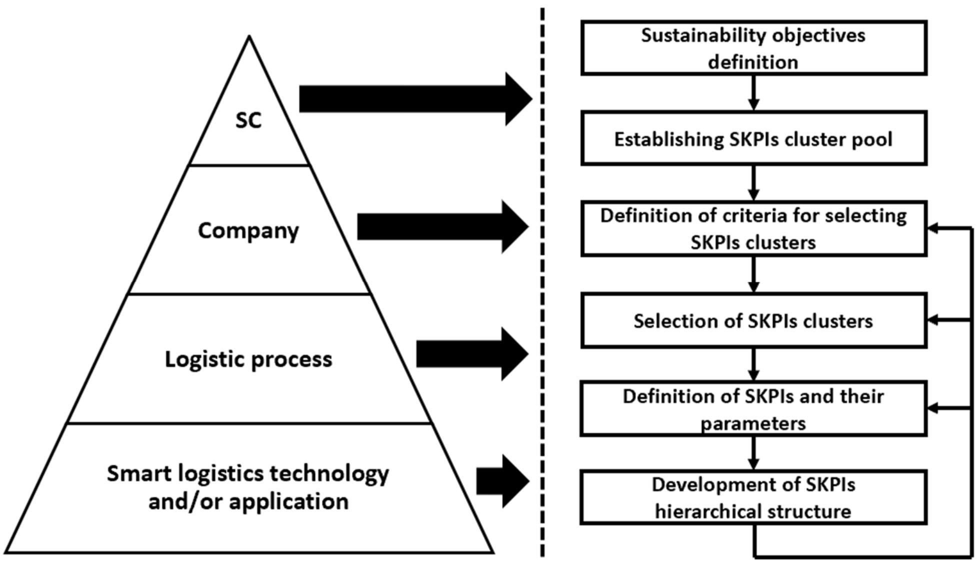

Figure 2 Methodology of SKPIs selection for assessing the sustainability of smart logistics

The methodology can be applied separately at different management levels (see Figure 2): supply chain, enterprise, logistics process and smart logistics technology and application. However, the sustainable performance of smart logistics should preferably be monitored and assessed at all levels. The sustainable performance of implemented smart logistics technologies and applications shall be assessed at lower management levels. Subsequently, this translates into overall sustainable performance at higher management levels.

The methodology relies on six steps shown in Figure 2 and is described in detail in the next section of the chapter.

4.1 Sustainability objectives definition

The SKPIs must be based on the sustainability strategy of the company and the supply chain, especially their sustainability objectives. Thus, the first step of the proposed methodology is the definition of sustainable objectives; the implementation of smart logistics technologies and applications should support their achievement. These objectives can represent a normative standard for a company or supply chain and apply to all stakeholders [35]. Thus, the final set of SKPIs shall be a balanced set reflecting the concerns of all stakeholders.

4.2 Establishing SKPIs cluster pool

Next, it is necessary to identify potentially suitable clusters for each sustainable goal, i. e., to create a sufficiently large SKPIs cluster pool. The following sources can be used:

a) SKPIs clusters that have already been defined in the company or supply chain as a result of other business processes;
b) SKPIs clusters from the literature review. To do so, one may apply the cluster analysis results from Chapter 3.1. The frequency analysis also allows the scientific community to assess the relevance of individual clusters;
c) SKPIs clusters recommended by corporate practice. In this case, a respected source is the Guidance on Core Indicators for Entity Reporting on Contribution towards Implementation of the Sustainable Development Goals developed by UNCTAD. The clusters contained in the Guidance are presented in Chapter 3.2, including a frequency analysis of their application by European industry leaders;
d) Design of own SKPIs clusters not included in the resources mentioned above.

The sources listed may overlap, see Figure 3, with dots representing SKPIs clusters. For example, a company or a supply chain may already use SKPIs clusters recommended by the scientific community and/or business practice.

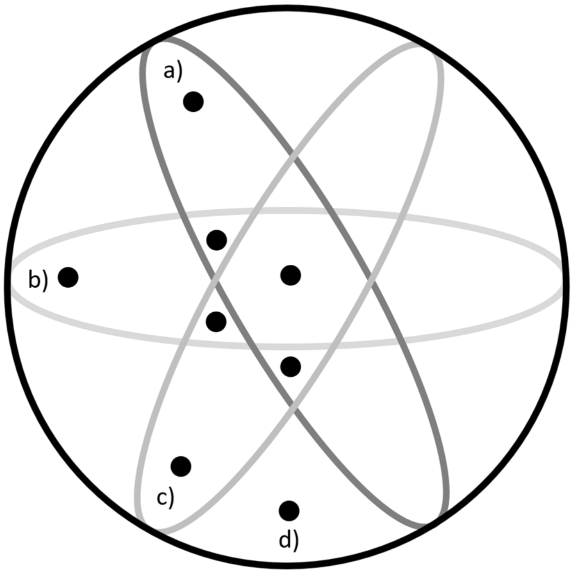

Figure 3 Sources for SKPIs cluster pool and their overlap

4.3 Definition of criteria for selecting SKPIs clusters

The next step in developing a functional and effective SKPIs system is determining the criteria for selecting suitable SKPIs clusters. A company or supply chain's main criteria should include:

1. Relevance to sustainable objectives. The SKPIs clusters should most closely reflect the achievement of the defined sustainability objectives.
2. Relevance to smart logistics. The SKPIs clusters should most closely mirror the change in sustainable performance associated with implementing smart logistics technologies and applications.

4.4 Selection of SKPIs clusters

This step involves applying the defined criteria for shortlisting the SKPIs clusters. As a rule, it shall include a qualitative assessment of whether or not the SKPIs clusters from the pool meet the defined criteria. Appropriate multi-criteria decision-making methods can be used to increase the assessment's objectivity.

4.5 Definition of SKPIs and their parameters

If suitable SKPIs clusters have been selected, the next step is to define one or more SKPIs for each of them. In defining them, one should remember that the final set of SKPIs must be manageable [25]. Therefore, it is better to choose a smaller number of SKPIs. To this end, it may be preferable first to define a broader set of possible SKPIs and, subsequently, identify those critical to the SKPI clusters.

SKPIs can be quantitative or qualitative. The best approach involves a combination of both methods [20]. In terms of expression, absolute or relative SKPIs can be used. Absolute SKPIs are more suitable for their gradual aggregation to higher management levels and in-house benchmarking. The chosen SKPIs should be straightforward and specific to avoid misunderstandings and allow comparison over time.

A clearly defined benchmark must be assigned to each SKPIs. When a new measure is necessary, the company or supply chain should consider appropriate measurement methods, costs, and time [35]. To improve the sustainable performance of a business or supply chain, it is also advisable to set a target value for each SKPIs.

4.6 Development of SKPIs hierarchical structure

The procedure should result in a reasonably simple, functional, and efficient SKPIs system. Figure 4 illustrates the recommended hierarchical structure of sustainable pillars, clusters, SKPIs, measures and targets. Developing such a system usually requires retracing the previous steps and reassessing their content (see feedback in Figure 2). For implementing the system designed in such a way, applying the methodology for aggregated sustainability performance assessment of an industrial corporation developed by Wicher et al. [56] is recommended.

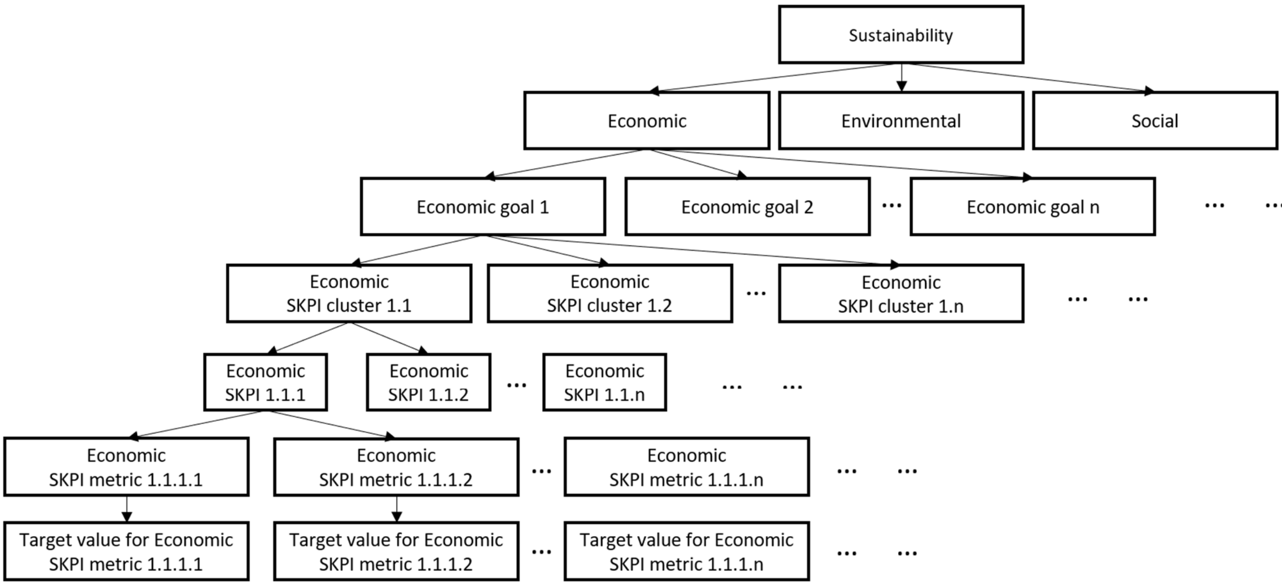

Figure 4 General hierarchical structure of SKPIs

5 Conclusion

This paper aimed to propose a methodology for selecting SKPIs suitable for assessing the sustainability performance of smart logistics and its technologies and applications. To accomplish the objective, two research questions have been addressed:

1. Which SKPIs can be applied to assess the sustainability performance of smart logistics and its technologies and applications? To do so, decision-makers can draw on a variety of sources. The proposal suggests combining SKPIs already in place in the company or supply chain with indicators recommended by the scientific community and business practice. Therefore, two analyses were conducted: a cluster analysis of SKPIs obtained through a review of the relevant literature and a frequency analysis of the use of the UNCTAD-recommended SKPIs in practice. Analyses have demonstrated that the primary focus should concentrate on investments and revenues in the field of Economy, emissions and waste management in the Environment, and occupational health and safety in the Social area.
2. How to select the appropriate SKPIs to assess the sustainability performance of smart logistics and its technologies and applications? While seeking an answer to this question, a SKPIs selection methodology for assessing the sustainability of smart logistics was proposed, involving defining sustainability objectives, creating SKPIs cluster pool, defining selection criteria applicable to SKPIs clusters, selecting SKPIs clusters, defining SKPIs and their parameters, and creating a hierarchical structure of SKPIs. The methodology can be applied separately at different management levels: supply chain, enterprise, logistics process and smart logistics technology and application.

While conducting research, we have revealed a distinct lack of a clear definition of smart logistics technologies and applications at different levels of the process, enterprise and supply chain management, both in the relevant literature and corporate practice. This ambiguity significantly complicates any assessment of sustainability performance in deploying the technologies. Therefore, the first objective of our further research is to propose an explanatory model for defining smart logistics technologies and applications at all management levels. The next step of any future research shall involve applying the established methodology and explanatory model as a baseline for developing a conceptual model to assess the sustainable performance of smart logistics in supply chains, balancing the economic, environmental and social performance of logistics processes.

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