The role of sustainability competences for IT systems engineers

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Abstract. Designing modern systems requires technical knowledge and sustainability competencies from engineers, as almost every system or product designed has a sustainability impact. This gained additional significance after adopting the Sustainability Development Goals in 2015 and their subsequent integration into the activities of enterprises and other entities and the products and services they offer. For this reason, the study's main goal was to determine the role of sustainability competences in activities performed by systems engineers. Sustainability competences and systems engineering competencies were analyzed. A significant overlap in many areas was found. Subsequently, the perception of these competencies by representatives of enterprises was examined. The results indicate that system engineers' perception of sustainability competences is not uniform, particularly depending on the size of the enterprise and position in the company hierarchy. Engineering team leaders and management pay more attention to soft skills. The study's results may help understand the relationships between competencies, support the development of HR processes, and entities offering training programs for employees at different career stages.

Keywords: Sustainability Competences, Systems Engineering Competencies, IT Engineers Career.

1 Introduction

In an era where sustainability is becoming a critical differentiator, information technology (IT) systems engineers who implement computational science results and possess these sustainability competences (SC) might enhance their value and enable their organizations to remain competitive, responsible, and innovative [3]. Sustainability is a

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broad concept that includes environmental protection along with social and economic aspects, aiming to meet the needs of current and future generations without depleting natural systems [5]. It involves managing interconnected elements like energy efficiency [31], resource use, and carbon footprint [35], which is challenging, especially in complex engineering IT projects [38] or interdisciplinary projects to support the achievement of the Sustainable Development Goals (SDGs) [2].

This study directly links sustainability to characteristics that integrate environmental considerations across the entire product and system lifecycle. Designing and offering sustainable products and acting sustainably enable companies to advance in their markets. For example, sustainability is becoming a key criterion in supplier selection within global markets. With increasing emphasis on sustainable development, systems engineers are uniquely positioned to embed sustainability principles throughout the product lifecycle [14]. They coordinate cross-functional inputs, align technical requirements with sustainability goals, and ensure environmental, economic, and social impacts are considered at every stage. A systems thinking approach is increasingly necessary to address sustainability challenges, combining environmental, financial, and social objectives. Designers must integrate sustainability factors throughout the lifecycle [19]. Systems engineers, who connect the entire design and development process, need sustainability competencies and technical and project management skills. There is no universally accepted set of sustainability competencies (SC) for systems engineering education. The lack of standardized SC leads to diverse approaches [23, 29, 38], often failing to meet modern job market demands and sustainable development challenges [30]. Additionally, there is a limited understanding of how specific SC translates into organizational benefits, hindering the identification of training needs and the development of appropriate education programs [4, 29]. IT systems engineers require technical skills in computational science and systems design, along with competencies in sustainability, project management, and interdisciplinary collaboration. Balancing these areas poses significant educational and practical challenges [29].

This article identifies and analyzes sustainability-related skills critical for IT systems engineers to contribute effectively to sustainable development. It explores how incorporating sustainability competencies improves IT system design, optimizes resource efficiency, reduces environmental impact, and supports sustainable development principles. The study examines how these skills influence daily work, professional development, and competency management. In-depth interviews investigated awareness of sustainability competencies and their impact on IT systems engineers' evaluation, compensation, and promotion from personal and organizational perspectives. Publications on "systems engineering competencies" (SEC) in Scopus date back to 2005, when MITRE Corporation discussed building SEC through on-the-job activities while enhancing systems engineering training programs [39]. The topic has been widely discussed in academia and industry [18, 20]. Several authors emphasized embedding SEC in engineering education curricula [12, 28, 37, 41]. [40] presented a methodology to improve feedback between employers and education institutions. [13] addressed SEC self-improvement, and a self-assessment tool was validated by [6]. Defense departments widely use competence models in systems engineering. For instance, the

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Australian DoD developed a portfolio of 30 competencies [15], and the US DoD created a model with 44 competencies [42, 43]. The International Council on Systems Engineering (INCOSE) comprehensively categorized and defined SEC into five categories: core, professional, management, technical, and integrating, with 36 detailed competencies. Each competency is described by levels of possession (awareness, supervised practitioner, practitioner, lead practitioner, expert) [16]. [18] introduced "Retirement" as a technical competency area. The framework applies to human resource management as outlined in the INCOSE Systems Engineering Handbook [17], encompassing recruitment, worker appraisals, promotions, compensation decisions, and training requirements. The framework has been successfully implemented across industries [11]. SEC considered in this research are detailed in [16] (see Table 1 for an extract).

Table 1. Systems Engineering Competencies based on [16].

Set of competencies	Description	Key Aspects
Core Systems Engineering	Utilization of systems thinking, lifecycle management, capability engineering, critical thinking, as well as systems modeling and analysis during system design and development.	Systems approach, systems modeling, lifecycle.
Professional	Utilization and establishment of behavioral competencies in the human resources domain, including communications, ethics, technical leadership, team dynamics management, coaching, and mentoring.	Team management, ethics, communication.
Technical	Engineering activities covered from the requirement definition through design, verification, and validation, as well as after transition operation and support and at the end of system retirement.	Requirement management, system architecting, interface management, verification, and validation.
Systems Engineering Management	Systems Engineering activities focused on planning, monitoring and control, decision management, business and enterprise integration, information management, and configuration management.	Planning, monitoring and control, information management.
Integrating	Incorporating project management, finance, logistics, and quality management into engineering activities.	Project management, quality management.

SC are widely examined in academic literature on education for sustainable development. Works [1, 7, 32] define key sustainability competences and explore how higher education fosters them. A detailed picture emerges of the nature of these competences, their interrelationships, and methodologies for analysis. [32] highlights competences like critical thinking, systemic thinking, and normative skills, essential for engaging with the complexity of sustainable development. [7] builds a framework using qualitative and quantitative methods to assess how these competences interconnect, showing how their synergy enhances educational programs. The aggregation of research findings on SC was expanded by [1], identifying key competences recognized across stud-

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ies and analyzing their interrelations. This review links theoretical constructs to empirical findings [3, 44, 45]. [25] summarized SC studies, synthesizing works from [22, 34, 44] and proposing 12 competences (Table 2). The discussion included teaching specific competences through particular pedagogical approaches [24, 26]. These competences, validated in international contexts, serve as a solid foundation for empirical studies and were referenced in this paper [27].

Table 2. Sustainability Competences based on [27].

Competence	Description	Key Aspects
Systems Thinking	Understanding complex interactions within systems across various domains and scales, emphasizing key dynamics, feedback loops, and systemic impacts.	Comprehension, verification, systems modeling.
Interdisciplinary Work	Utilization and integration of diverse disciplinary knowledge and methods to solve complex problems, emphasizing collaborative problem-solving.	Knowledge evaluation, interdisciplinary integration.
Anticipatory Thinking	Proactive envisioning of future scenarios and their implications, applying principles such as the precautionary approach to manage potential risks and changes.	Future scenario planning, risk assessment, precautionary measures.
Justice, Responsibility, and Ethics	Emphasis on ethical conduct, justice, and responsibility, focusing on the impact of actions on social and ecological systems, and the negotiation and reconciliation of diverse values and goals.	Ethical integrity, social justice, responsibility for actions.
Critical Thinking and Analysis	Examination and questioning of existing norms and opinions, along with reflection on personal values and an understanding of alternative viewpoints.	Norm evaluation, self-reflection, external perspective analysis.
Interpersonal Relations and Collaboration	Skills in participatory problem-solving and project collaboration, using effective communication, negotiation, and leadership abilities.	Teamwork, communication, leadership.
Empathy and Change of Perspective	Identification with and sensitivity to the needs and perspectives of others, fostering an environment where diverse opinions are valued and integrated.	Compassion, empathy, diversity acceptance.
Communication and Use of Media	Effective intercultural communication and judicious use of information and communication technologies, with a focus on critical media evaluation.	Media literacy, digital communication efficiency.
Strategic Action	Strategic design and execution of sustainable projects and initiatives, focusing on leadership, risk management, and organizational control.	Project management, strategic planning, leadership.
Personal Involvement	Active engagement in sustainability efforts, marked by a willingness to innovate and self-motivate, coupled with a commitment to continuous personal and professional development.	Self-motivation, initiative, continuous learning.

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Assessment and Evaluation	Creation of standards for assessing and evaluating projects or policies, ensuring independence from conflicts of interest and adaptability in the face of uncertain information.	Independent evaluation, standards development, conflict management.
Tolerance for Ambiguity and Uncertainty	Effective management of ambiguity in decision-making processes, maintaining resilience and adaptability in situations involving conflicting goals, uncertainties, or setbacks.	Ambiguity management, resilience in uncertainty.

2 Methodological approach

A research strategy of theory building from multiple cases [8], particularly using structured multiple case study, was adopted [46], focusing on a few selected cases rather than many. This research strategy provides several methodological benefits [9]. First, it allows for a more in-depth and comprehensive analysis of each case, enabling the researcher to understand the specific contexts and nuances of the phenomenon being studied [36]. Furthermore, focusing on fewer cases can enhance the reliability and contextual richness of the findings. Fewer cases emphasize understanding specific local conditions, which can lead to more credible insights [10]. This is particularly important in qualitative research, where the value often lies in capturing the depth and complexity of individual cases rather than aiming for broad generalizations. Another significant advantage of focusing on fewer cases is its utility in theory building. As [8] argues, a smaller sample size enables a more iterative data collection and analysis process, which is conducive to developing theoretical frameworks. This process helps balance between detailed case-specific analysis and drawing broader theoretical insights.

This qualitative and exploratory research aims to generate hypotheses for broader quantitative studies. Researchers selected enterprises familiar with systems engineering and willing to participate in interviews, indicating some knowledge of sustainability. Participants and cases were chosen from current and former members of the Polish Chapter of INCOSE, representing various industries (Table 3) but focusing on embedded systems development or IT systems to ensure a wide perspective for future considerations. Unlike studies involving numerous cases that simplify analysis for generalization, a limited number of cases allows preserving each context's complexity and specific traits. [36] this approach yields more meaningful conclusions by integrating contextual insights without losing individual case details. Systems engineering focuses on technical and organizational aspects. IT system engineers naturally prioritize technological advancements and, even without explicit recognition of Industry 4.0 policies, are generally familiar with the latest technologies driving this paradigm. However, their understanding of Industry 5.0 pillars—such as human-centricity, resilience, and sustainability—remains uncertain. For a successful transition to Industry 5.0, system engineers must play a crucial organizational role, recognizing how decisions in the engineering process impact these pillars. This paper examines whether system engineers are prepared for the I5.0 era, focusing on the sustainability competencies (SC) expected of them. Fig. 1 depicts a three-step methodology.

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Table 3. Sample.

Industry	Company Size	Level of responders
Automotive	Large	Manager of SE
Automotive	Large	System Engineer
Automotive	Middle-sized	Engineering Director
Aviation	Large	System Engineer
Energy	Large	System Engineer
Space	Middle-sized	Manager of SE

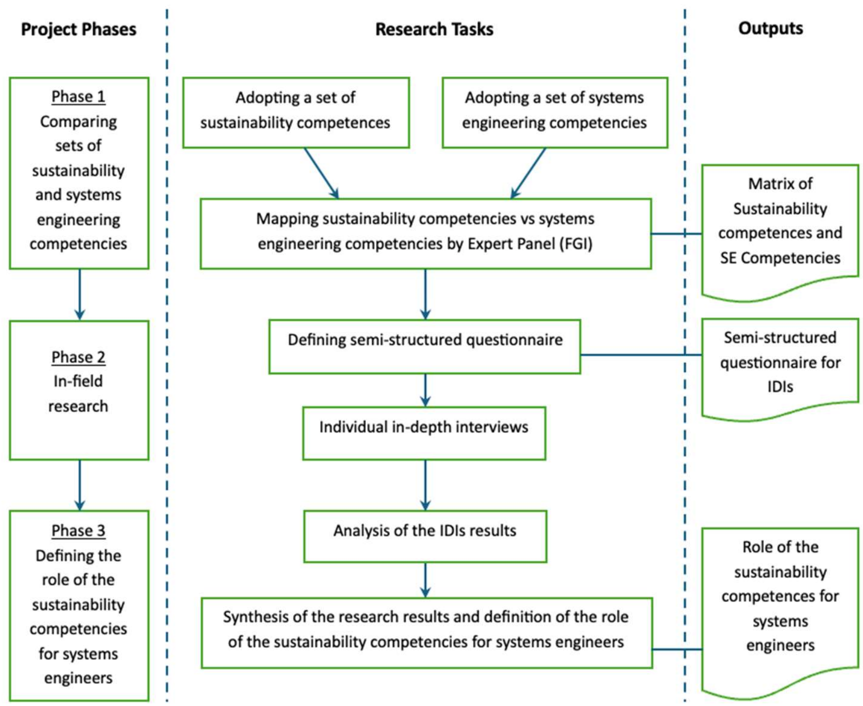

Fig. 1. Research procedure

First, the study examined whether prominent approaches to defining SC and SEC in IT and computational science contexts are consistent or differ. This was achieved through secondary data analysis conducted by domain experts during a Focus Group Interview (FGI). Three experts participated: one specializing in systems engineering, one in sustainability, and one with expertise in both areas. All experts had both academic and industrial experience. The secondary data included the systems engineering competency framework provided by the International Council of Systems Engineering

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[16] and a synthesized list of SC [26, 27]. A 2-dimensional matrix was created to compare the lists and assess how SC are recognized within systems engineering frameworks developed by professionals. Rows represented SEC, and columns SC. The matrix used symbols to indicate the degree of alignment: '+++' for full coverage, '++' for significant overlap, and '+' for partial overlap. This analysis's results informed the questionnaire's scope used in the next research phase. The second phase consisted of IDIs using a semi-structured questionnaire to gather the required data. Six respondents were interviewed, representing the automotive, aviation, space, and energy industries. Two respondents were involved in civil and defense projects. Five respondents were from engineering centers of large multinational companies in Poland, with extensive experience in systems engineering, embedded systems, and/or IT systems. Five were current or former members of INCOSE. Two respondents managed IT systems engineering teams. The interviews aimed to determine whether sustainability competencies are practically considered for IT systems engineers.

3 Results

The FGI and IDIs results provided material to analyze SC's role in systems engineers' daily work and development. This section presents a harmonized SEC framework, including SC, through a coverage matrix. SEC from the INCOSE handbook [17] were compared to SC [27]. Seeking stronger alignment of engineering education with the UN's SDGs, the notion of "global competence" has drawn growing attention, focusing on how engineers develop it, especially regarding sustainability goals. Section 1 discusses global competence for engineers concerning the SDGs. [35] presented the first attempts to integrate SDGs into engineering education, based on a logical framework. [21] advocate a design-based approach to enhance global competence in four areas: institutional frameworks, institutional diversity, competence training, and assessment. Figure 2 shows the results of the SC and SEC mapping. The Core SE Principles and Professional Competencies overlap with all SC. Professional Competencies correlate with extrospective-social and introspective-personal competences, while the Core SE Principles correlate with cogitative-processual competences, notably "systems thinking," which also correlates with several Technical Competencies (left of the V-model). There is a notable lack of correlations between SC and SE Management or Integrating Competencies. During the FGI, experts stressed the importance of HR processes (recruitment, evaluation, compensation, promotion), which influenced the questionnaire scope for the IDIs. Six interviews were conducted (three online). Their synthetic results, expanded in the discussion, show all respondents were aware of sustainability topics and recognized that organizations, including systems engineers, take them into account. Sustainability is often viewed through environmental protection. In large companies, formal sustainability policies are managed at the highest level, while in medium-sized companies, such policies also exist but are developed and maintained more ad hoc.

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		Extrospective-social				Introspective-personal				Cogitative-processual			
		Emphaty and change of perspective	Interpersonal relations and collaboration	Critical thinking and analysis	Communication and use of media	Justice, responsibility, and ethics	Tolerance for ambiguity and uncertainty	Inter-disciplinary work	Personal involvement	Strategic action	Anticipatory thinking	Systems thinking	Assessment and evaluation
Core SE principles	Systems Thinking											xxx	
	Lifecycles									x			
	Capability Engineering										x		x
	General Engineering												
	Critical Thinking	xx		x	x	x		x		x	x	xx	x
	Systems Modeling and Analysis			x								xx	
Professional Competencies	Communications	x	x		x				x				
	Ethics and Professionalism	x				xx			xx				
	Technical Leadership	x							xx				x
	Negotiation	x	x		x	x	x	x	x				
	Team Dynamics		x		x	x	x	xx					
	Facilitation	x	x		x	x		x	x	x			
	Emotional Intelligence	xx	x		x	xx	xx	x				x	x
	Coaching and Mentoring	x	xx		x	xx	xx	xx	x				
Technical Competencies	Requirements Definition									xx		x	
	System Architecting											x	
	Design for…											x	
	Integration											x	
	Interfaces												
	Verification												
	Validation												
	Transition												
	Operation ans Support												
SE Management Competencies	Planning									x			
	Monitoring and Control												
	Decision Management									x			
	Concurrent Engineering												
	Business & Enterprise Integration												
	Acquisition and Supply												
	Information Management												
	Configuration Management												
	Risk and Opportunity Management										x		x
Integrating Competencies	Project Management												
	Finance												
	Logistics												
	Quality												

Fig. 2. Mapping sustainability competences to INCOSE competency framework

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According to all respondents, sustainability-related competences are perceived as additional, while the key ones are the so-called technical competencies needed for systems design. SC, especially extrospective-social and introspective-personal, are considered during recruitment and promotions in large companies, according to responders holding managerial positions.

4 Discussion

4.1 Systems Engineering and Sustainability Competencies Gaps and Overlaps

SC and SEC significantly intersect, requiring an understanding of complex systems, lifecycle thinking, and long-term planning with impact assessment. The matrix (Fig. 2) shows these taxonomies overlap, and SEC includes SC, confirming that SE professionals value sustainability paradigms in SE processes. However, the taxonomies also differ significantly. There is no 1:1 match between SE and sustainability competences, and each SC overlaps partially with multiple SEC. The SEC covers most SC under "core SE principles" and "professional competencies." Analysis of relationships between systems thinking vs. strategic action outlines that systems thinking is essential for IT systems engineers, enabling them to understand how different system elements interact. It is equally critical in sustainability, where strategic actions must consider long-term environmental, social, and economic impacts. A strong relation is visible for emotional intelligence vs. empathy and change of perspective. Emotional intelligence, which includes understanding and managing one's emotions and empathy, is vital in cross-cultural and interdisciplinary collaboration in sustainable projects, where changing perspectives can lead to better understanding and acceptance of diverse interests and needs.

Table 2 may indicate the need to develop further management competencies in integrating sustainability throughout the product life cycle. It is also worth noting that technical competencies are directly linked to system design aspects, suggesting that implementing sustainability in design requires a more holistic approach at the management level. The lack of significant correlations between SE and SE management competencies and integrating competencies is particularly intriguing. SE management competencies, such as planning, risk, and information management, are crucial for guiding engineering projects toward sustainable outcomes. Weak connections with sustainability competencies may indicate that sustainability principles are not yet fully integrated into the management and decision-making processes that drive systems engineering. This gap highlights a missed opportunity to promote sustainability within the broader context of management and integration in systems engineering. The lack of connections could suggest that current management practices may be focused primarily on efficiency and effectiveness, potentially overlooking the long-term sustainability impacts of their projects. During the FGI, experts emphasized the need for a greater focus on human resource-related processes as key enablers for embedding sustainability throughout organizations. Addressing these areas could help bridge the gap, ensuring that sustainability becomes a core aspect of decision-making at all levels of systems engineering, particularly in the management and integration phases.

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It should be noted that core SE principles and professional competencies cover all three areas of sustainability. The relationship between professional competencies and sustainability is particularly strong. It can be inferred that a systems engineer should be skilled in all areas of sustainability and incorporate them into professional work. The competences that intersect most strongly are empathy and change of perspective, interpersonal relations and collaboration, communication, media use, justice, responsibility, and ethics, interdisciplinary work, personal involvement, strategic action, and systems thinking. This demonstrates that the systems engineer has highly developed interpersonal skills, can collaborate with others, is responsible, ethical, and highly committed to the tasks. Importantly, system engineers can use multiple media and think strategically and systemically.

Very few technical and management competencies overlap with the sustainability dimensions. This may be evidence that when moving from the general to operational (technical and management) level of professional competence, there is a lack of consideration of the sustainability and triple bottom line perspective. The systems engineer knows the importance of sustainability in professional work, but does not consider sustainability guidelines/recommendations in many detailed tasks. It is worth noting that none of the integrating competencies overlap with sustainability. This may indicate that it is difficult to directly demonstrate sustainability aspects with complex competences, requiring knowledge and skills in many areas (e.g., Quality, Logistics, Finance. Each competency could be broken down into smaller areas and defined in terms of the required sustainability competences. For example, in Logistics competence, interpersonal relations and collaboration with partners in the supply chain are very important. This is a research gap; further research is worthwhile to establish why these competences do not overlap. Admittedly, systems thinking and strategic action are found in technical and management competences. This is also confirmed by the fact that the systems engineer often has a strategic/systems view of the tasks performed in the context of sustainability, but without focusing on their implementation into operational activities (e.g., validation, planning, etc.). In the education of system engineers in the context of sustainability, the focus is on general professional competences (strategic level), to the extent that the development of practical competences (operational level) is lacking.

4.2 Sector- and competence-type-specific insights

IDIs confirmed differences in the perception of sustainability between large and medium-sized enterprises (SMEs). Large companies consider sustainability at the corporate level through internal policies rather than in the daily activities of systems engineers. For example, a company in the space and electronics sector applies sustainability principles mainly at the mission level, focusing on Clean Space policies. Although IT systems engineers consider these principles during the design stage, the organizational culture does not require them to implement these competencies daily. Companies from the energy sector demonstrate sustainability awareness, especially in terms of social responsibility and energy management. Still, these practices are mostly managed by HR and organizational policies, with systems engineers not directly involved in daily

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implementation. In companies from the aviation sector, sustainability is embedded in processes and policies related to product design. Still, the daily tasks of systems engineers focus more on following these guidelines rather than actively creating sustainable solutions. Companies operating in the automotive sector strongly emphasize the involvement of systems engineers in implementing sustainable practices, especially in team building, work environment, and individual actions. Sustainability in these companies is more visible at the operational level, with systems engineers actively applying competencies such as empathy, collaboration, and flexibility. Organizational sustainability awareness is limited, showing these practices rely more on the initiative of individual engineers than on formal company policies. The company prefers a bottom-up approach, where engineers can incorporate sustainable practices into daily work.

Large companies addressed sustainability at the managerial level. They are mainly implemented through internal policies, while in medium-sized companies, systems engineers are directly involved in applying sustainable practices at the operational level. Responses across industries demonstrate that technical knowledge and familiarity with engineered systems are paramount for systems engineers. Systems thinking emerges as a core competency, enabling engineers to analyze and model complex interactions. Activities like stakeholder needs definition, system architecting, and integration are central to their roles, requiring detailed technical expertise. Respondents highlighted reliance on structured methodologies like the V-model and INCOSE guidelines for consistency and precision in system design and validation. Moreover, technical processes like requirements definition, interface control, and system verification are prioritized in daily operations. These tasks demand a granular understanding of system interactions and technical functionality, underscoring their criticality. Systems engineers are also expected to propose solutions to complex challenges, such as integrating new components into existing infrastructures, as noted in the energy and aerospace sectors. Career development within the field emphasizes technical accomplishments, with evaluations often centered on functional outcomes and system delivery. Interpersonal and sustainability-related competencies are acknowledged but remain secondary to technical expertise in systems design and implementation. This widespread prioritization across various domains underscores the centrality of technical knowledge for systems engineers.

The interviews reveal that soft skills are acknowledged as valuable, particularly in hiring and promotion processes. Some respondents emphasized interpersonal abilities like collaboration, communication, and leadership during recruitment. For example, one company uses critical thinking tests and assesses interpersonal dynamics in hiring. In promotion scenarios, soft skills like teamwork and emotional intelligence are often factored into evaluations, as they help build trust and foster effective team environments. Technical knowledge remains a primary determinant in performance evaluations and advancement. Respondents highlighted that assessments often focus on tangible outputs, like project delivery and adherence to technical standards. Engineers are evaluated on their ability to apply methodologies like systems thinking, requirements definition, and integration, reflecting their technical proficiency. These criteria are pivotal for advancing their roles, especially in highly technical fields like aerospace and energy systems. Computational science and AI skills are crucial for systems engineers: utilizing them daily and incorporating, in particular, AI solutions in designed systems

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[20]. Soft skills are increasingly recognized for supporting teamwork and leadership, and technical expertise dominates the evaluation framework. This dual emphasis ensures engineers are technically competent and can navigate interpersonal and organizational challenges critical for long-term career growth. The IDIs suggest soft skills are often more crucial than technical knowledge for management. Respondents emphasized that leadership roles prioritize fostering effective team dynamics over individual technical excellence. Managers highlighted the value of interpersonal skills like collaboration, empathy, and conflict resolution in maintaining team cohesion. For example, one respondent noted that aligning work with team members' predispositions and ensuring a balance between work responsibilities and personal well-being enhances team trust and productivity.

4.3 Other insights

Severe organizations stressed that a cohesive team consistently outperforms groups dominated by high-performing individuals who create conflict. Managers reported prioritizing skills such as communication, emotional intelligence, and adaptability when deciding promotions to leadership positions. These competencies enable leaders to build trust, manage uncertainty, and navigate organizational challenges effectively. In essence, technical skills remain essential for systems engineers; leadership roles require a shift in focus toward managing relationships and fostering a collaborative environment. This ensures that teams can collectively achieve their goals without being disrupted by interpersonal conflicts or siloed expertise.

IDIs support the statement that managers perceive sustainability competences as very important in their careers. Sustainability-related issues should be included in higher education programs addressed to experienced employees, including MBA programs, etc. [33]. The same applies to AI/ML solutions in designed systems [47]. Large companies are usually better prepared to develop systems engineering and sustainable development competences. They often have greater resources. That allows them to integrate a wider range of skills and practices, including sustainability-related ones. Smaller companies focus on core competences/activities that directly generate added value. Therefore, many sustainability-related competences and activities are often perceived as indirectly related to the core business activity, making it difficult to prioritize them and invest in sustainability initiatives. While systems engineers focus more on technical and project management skills within defined systems, experts with sustainability competences emphasize environmental knowledge and ethical advocacy within broader ecological and social systems. Both contribute crucially to addressing complex, interdisciplinary challenges in today's world.

5 Conclusion

The study determined the role of SC in activities performed by systems engineers. The results indicate that systems engineers' perception of SC is not uniform and particularly depends on the enterprise's size and position in the company hierarchy. The study's key

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findings highlight several important insights. First, sustainability competencies (SC) and systems engineering competencies intersect significantly, although the competency taxonomies for both fields show notable differences. Human resource-related processes are identified as crucial enablers for embedding sustainability throughout organizations, emphasizing their role in facilitating sustainable practices. Systems engineering principles and professional competencies encompass all three dimensions of sustainability; however, only a limited overlap exists between technical and management competencies and sustainability, and none of the integrating competencies in systems engineering align with sustainability. The research also revealed differences in the perception and integration of sustainability between large enterprises and small-to-medium-sized enterprises (SMEs). Variations were observed across different industry sectors, highlighting the need for tailored approaches to sustainability. Managers regard SC as highly significant in their professional development and career progression. Future research should explore several key areas. One focus should be on how sustainability can be more effectively integrated into the technical, management, and integrating SEC. Another critical question is how operational and practical sustainability methods, principles, and tools can be better utilized to implement complex engineered systems. Supporting SMEs in enhancing their sustainability activities and performance is another priority, addressing smaller organizations' unique challenges. Lastly, research should investigate strategies to integrate sustainability more effectively into managers' and leaders' education and training programs, ensuring they can drive sustainable organizational initiatives.

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