The Journal of Systems and Software 211 (2024) 111978

Contents lists available at ScienceDirect

The Journal of Systems & Software

journal homepage: www.elsevier.com/locate/jss

Sustainability competencies and skills in software engineering: An industry perspective☆

Rogardt Heldal [a,*], Ngoc-Thanh Nguyen [a], Ana Moreira [b], Patricia Lago [c], Leticia Duboc [d], Stefanie Betz [e,i], Vlad C. Coroamă [f,g], Birgit Penzenstadler [h,i], Jari Porras [i,l,n], Rafael Capilla [j,i], Ian Brooks [k], Shola Oyedeji [i], Colin C. Venters [l,m]

[a] Western Norway University of Applied Sciences, Norway
[b] NOVA LINCS, School of Science and Technology, NOVA University Lisbon, Portugal
[c] Vrije Universiteit Amsterdam, Netherlands
[d] La Salle, Universitat Ramon Llull, Spain
[e] Furtwangen University, Germany
[f] Roegen Centre for Sustainability, Switzerland
[g] Technische Universität Berlin, Germany
[h] Chalmers University of Technology, Sweden
[i] LUT University, Finland
[j] Rey Juan Carlos University, Spain
[k] University of the West of England Bristol, UK
[l] University of Huddersfield, UK
[m] European Organization for Nuclear Research (CERN), Switzerland
[n] Aalto University, Finland

ARTICLE INFO

Dataset link: https://bit.ly/390MQju, https://bit.ly/3wgt0dp

Keywords:
Sustainability
Software engineering
Education
Software competencies
Sustainable development goals
Skills

ABSTRACT

Context: Achieving the UN Sustainable Development Goals (SDGs) demands a shift by industry, governments, society, and individuals to reach adequate levels of awareness and actions to address sustainability challenges. Software systems will play an important role in moving towards these targets. Sustainability skills are necessary to support the development of software systems and to provide sustainable IT-supported services for citizens.
Gap: While there is a growing number of academic bodies including sustainability education in engineering and computer science curricula, there is not yet comprehensive research on the competencies and skills required by IT professionals to develop such systems.
Research goal: This study aims to identify the industrial sustainability needs for education and training from software engineers' perspective. For this, we answer the following questions: (1) what are the interests of organisations with an IT division with respect to sustainability? (2) what do organisations want to achieve with respect to sustainability, and how? and (3) what are the sustainability-related competencies and skills that organisations need to achieve their sustainability goals?
Methodology: We conducted a qualitative study with interviews and focus groups with experts from twenty-eight organisations with an IT division from nine countries to understand their interests, goals, and achievements related to sustainability, and the skills and competencies needed to achieve their goals.
Results: Our findings show that organisations are interested in sustainability, both idealistically and increasingly for core business reasons. They seek to improve the sustainability of software processes and products but encounter difficulties, like the trade-off between short-term financial profitability and long-term sustainability goals or an unclear understanding of sustainability concepts from a software engineering perspective. To fill these gaps, they have promoted in-house training courses, collaborated with universities, and sent employees to external training. The acquired competencies should support translating environmental and social benefits into economic ones and make sustainability an integral part of software development.

☆ Editor: Alexander Serebrenik.

* Corresponding author.
E-mail address: rohe@hvl.no (R. Heldal).

https://doi.org/10.1016/j.jss.2024.111978
Received 25 June 2023; Received in revised form 15 November 2023; Accepted 19 January 2024
Available online 2 February 2024

1. Introduction

Digitalisation is pervasive and can either help or hinder the United Nations Sustainable Development Goals (SDGs)[1] (Seele and Lock, 2017; Coroama and Mattern, 2019). Organisations understand that but struggle to implement sustainability in their service portfolio and their business practices (Escoto et al., 2022; Bocken and Geradts, 2020). Consequently, there is a need to understand which competencies and skills industry requires, and how they can be integrated into their practices. These new competencies and skills must be acquired through adequate learning programmes and courses addressing the different sustainability dimensions, i.e. environmental, economic, social, technical, and individual (Becker et al., 2015b). For software engineers,[2] this ranges from the more technical aspects supporting Green IT and software sustainability to more social and individual ones facilitating software-driven processes in society.

Academia made efforts to introduce sustainability in regular computer science programmes, as well as suggesting the skills and competencies needed by their students (Watson et al., 2013; Stone, 2019; Rogers et al., 2015). According to these studies, future software engineers need to develop a sustainability mindset and acquire sustainability competencies able to produce sustainable IT-based systems or systems that both support more sustainable processes and monitor the achieved sustainability goals (Mann, 2011). However, industry is still unclear on which sustainability skills different sectors require to achieve their sustainability goals.

Recent non-academic literature highlights the role and importance of skills for sustainability. For instance, even the British Plastic Federation (Judith, 2022) mentions that the sustainability skills of employees are key for any strategy oriented toward achieving a sustainable business. Similarly, Terrafinity (2023), a sustainability consultancy, highlights that effective sustainability performance demands sustainability skills and competencies — not only from sustainability professionals but also in other roles within the organisation. Hence, we not only need to identify which skills are more relevant in delivering sustainability in a particular organisational unit but also related units must recognise sustainability as a goal of the company's core business.

What prompts this study is that we, the authors, are under the impression that across industry there is (1) only a partial understanding of sustainability and there is (2) a limited understanding of how to address the lack of related competencies. Additionally, across academia, there is (3) a lack of understanding of the needs of industry related to sustainability and (4) a need for a concrete teaching curriculum that could lead to the high-quality sustainability education that software engineers require.

This work aims to investigate the industrial sustainability needs for education and training from a software engineering perspective. To achieve this, we addressed the following three research questions: RQ1: *What are the interests of organisations with an IT division with respect to sustainability?*; RQ2: *What do organisations want to achieve with respect to sustainability, and how?*; and RQ3:*What are the sustainability-related competencies and skills that organisations need to achieve the established sustainability goals?* To this end, we interviewed sustainability and IT experts from twenty-eight (28) organisations in nine (9) different countries. Our main contributions are:

- A far-reaching overview of the organisations' perspective on sustainability, including (i) their general interest in sustainability; (ii) the sustainability goals they want to achieve; (iii) their achievements towards these goals and the difficulties faced in achieving them; (iv) the sustainability skills and competencies they already possess in-house and those that are missing; and (v) solutions to acquire the missing skills.
- Initial insights on the gaps in current academic and non-academic training programmes for software engineers.

The rest of the paper is structured as follows: Section 2 provides a comprehensive background of the concept of sustainability and discusses related work. Section 3 elaborates on the employed research method. Section 4 presents the results regarding competencies and skills. Section 5 interprets the study's findings. Section 6 compares our study with related works. Section 7 provides an analysis of the threats to validity. Lastly, Section 8 concludes the study and highlights potential future research directions.

2. Background and related work

This section provides the background on the general notion of sustainability and its relationship to IT and Software Engineering. It then presents related work.

2.1. Sustainability in software engineering

Although the principles of sustainability have been known to numerous human cultures throughout history, their first scientific usage was most likely in Von Carlowitz (1732) principles of sustainable forestry from 1713 (summarised in Morgenstern (2007)). As Hilty and Aebischer (2015) comment, as the understanding at the time was that forests have one purpose, to produce wood, Carlowitz's basic principle is quite straightforward: "*do not cut more wood than will grow in the same period of time*". Of course, we know today that a forest accomplishes many further functions (such as producing oxygen, filtering air and water, preserving biodiversity, recreational and aesthetic values, and many more), which makes the sustainability perspective much more complex. The paradigm, however, is unchanged. As Venters et al. (2018) discuss, the verb "to sustain" and the noun "sustainability" come from the Latin "sustenere", which was used for both "to endure" and "to uphold" something. Hence, "sustainability" refers to the capacity of a system to endure for a certain amount of time. Within the conceptualisation of sustainability put forward by the Brundtland (1987) Commission in 1987, the system in question is Earth itself and the period of time, while not exactly specified, includes many generations into the future. The Brundtland definition thus encompasses two aspects: distributive justice ("*the essential needs of the world's poor, to which overriding priority must be given*"), but also intergenerational justice, for which the preservation of the biosphere is a prerequisite.

The relationship between the IT sector (or digitalisation in general) and sustainability has been conceptualised in various ways and under different names. Early concerns with the environmental footprint of the IT sector itself are usually referred to as "Green IT", while the purposeful deployment of IT to reduce the environmental footprint in other economic or societal sectors is often called "Green by IT" (Coroama and Hilty, 2009). Other terms used to describe the latter are, for example, ICT4EE (ICT for energy efficiency), "Energy Informatics" (Hilty and Aebischer, 2015) or "I(C)T enabling effect" (Malmodin et al., 2014). Numerous further names describe the relationship between digitalisation and sustainability in general, which includes both the concepts of "Green IT" and "Green by IT", but also the further dimensions of sustainability, in particular, the social one. Such names include "Digital Sustainability", "Sustainable Computing" or "ICT for Sustainability (ICT4S)" (Hilty and Aebischer, 2015).

For the "software and sustainability" domain, there are also two views, which are quite similar to those of the broader "IT and sustainability" field (Lago et al., 2013): one looking at the sustainability of software itself (foremost, thus, a technical notion of sustainable software), the other at deploying software engineering for sustainability (SE4S) beyond the software systems themselves (Venters et al., 2018). Acknowledging both views, the "Karlskrona Manifesto for Sustainability Design" extends the well-known three dimensions of sustainability

[1] https://sdgs.un.org/goals.

[2] The term "software engineer" in this article includes anyone who takes part in the process of designing, producing, and managing software.

(i.e., environmental, social, and economic) by another two: technical (to account for the desired long-term use of software) and individual (addressing personal freedom, dignity, and fulfilment) for a total of five dimensions (Becker et al., 2015b). While the individual dimension is not always represented, most literature in the field accounts for both the technical as well as the three established dimensions (environmental, economic, and social) (Lago et al., 2015). As is the case in general with sustainability, the dimensions are not entirely independent and there are often trade-offs among them (Becker et al., 2015a). And while current software engineering practice gives high value to the technical and economic dimensions, the social and environmental ones (and thus the crucial components of the sustainability concept as understood by the Brundtland commission) are often ignored (Lago et al., 2015).

2.2. Related work

A number of studies have investigated how software engineering professionals understand sustainability. For example, Groher and Weinreich (2017) report on a qualitative interview study with ten interviews in nine organisations in Austria. They aimed to comprehend how practitioners understood sustainability and its importance, the factors influencing sustainability in software development, sustainability-related deficiencies in their projects, and how they improve sustainability in such projects. The results show that while practitioners find the topic of sustainability important, they seem to have a narrow view of sustainability, focusing mainly on technical attributes such as maintainability and extensibility. In addition, practitioners were concerned with organisational and economic issues, but the environmental dimension was not addressed.

de Souza et al. (2014) discuss software sustainability as perceived by nine software developers from a university in the UK, and suggest a set of recommendations on how to improve the sustainability of software. They used short, semi-structured interviews, each lasting an average of about 10 min. The main result is the distinction between "Intrinsic Sustainability", referring to intrinsic characteristics software should have (e.g., be documented, be tested, or be modular), and "Extrinsic Sustainability", referring to the environment in which the software is developed or used (e.g., be open, be actively maintained, or be infrastructure-independent). The authors proposed a set of recommendations as good practices for software development and maintenance that directly emerge from the characteristics interviewees associated with 'intrinsic' or 'extrinsic' sustainability but remain exclusively in the realm of technical sustainability.

Karita et al. (2021) report on a study performed with ninety-nine companies from the software industry in Brazil to investigate their awareness of four sustainability dimensions (environmental, economic, social, and technical). The results indicate that sustainability in the context of Software Engineering is a new subject for practitioners, that they find the topic relevant, and that sustainability should be treated as a quality attribute.

Chitchyan et al. (2016), interviewed thirteen requirements engineers from eight different countries (Austria, Brazil, Germany, Spain, Switzerland, Turkey, the UK, and the USA). The study investigated the perception of engineering practitioners towards sustainability as well as obstacles and mitigation strategies regarding the application of sustainable design principles in their engineering work. The study shows that on an individual level, perceptions of sustainability tend to be narrow, organisations are not aware of the potential achievements and benefits coming along with sustainable design, and the standards and norms in Software Engineering are not conducive to sustainability.

Other published work is more loosely related to ours, with the following worth highlighting. Betz et al. (2022) investigated the role of perception of software engineers; more specifically the self-attribution of software engineers and whether they implement sustainability issues in their daily work. The results suggest that software engineers perceive that they are insufficiently involved in the design process and that they do not sufficiently take on responsibility for the software and its sustainability impacts. The authors observed an evolution in terms of communication with interdisciplinary experts, yet their software engineers still see themselves as a "purely executive force", who shy away from responsibility regarding sustainability. Additionally, a domain-specific study conducted by Kasurinen et al. (2017), investigated – among other points such as the development processes used – the extent to which game developers are concerned about sustainability issues and Green IT. The results show that their interviewed gaming companies were more unstructured than general software development ones, not really incorporating sustainability in their daily work practices.

In the related field of Information Systems (IS), Cooper and Molla (2017) investigated the notion of the "absorptive capacity" of IS to enable environmental sustainability and how organisations can enable IS changes to address environmental issues. They conducted a survey with 148 IS senior managers and provided different taxonomies to acquire knowledge about sustainable IS and to what extent IS sustainable technologies are assimilated by organisations. The role of "absorptive capacity" is also discussed in Dzhengiz and Niesten (2020), where the authors provide a systematic literature review on competencies for environmental sustainability and managerial skills required for organisations to transform knowledge into environmental capabilities. The work suggests a connection between environmental competencies and capabilities, and they provide a taxonomy between management and environmental competencies.

3. Study design and research method

To answer our research questions, we used a mixed-methods approach (Easterbrook et al., 2008), combining individual interviews and focus group interviews in a semi-structured format. For the sake of brevity, both individual interviews and focus group interviews are referred to as interviews hereafter. Our study process is illustrated in Fig. 1. In summary, we extensively discussed our research goals and steps (study design and planning), creating a set of PowerPoint slides to guide our conversations in all interviews and focus groups (data collection). Additionally, we did a pilot study that provided a baseline structure for the subsequent interviews. All interviews were recorded and transcribed and the relevant information was retrieved with the support of a code book (data extraction). Then, the coded data was analysed and the results presented.

3.1. Goals and research questions

To address our eventual goal (i.e., design education programmes that teach the required sustainability competencies and skills for future software engineering), we first need to understand what are the needs of the field, i.e., from industry.[3] Accordingly, we formulate the following overarching research question (RQ): "*What are the industrial sustainability needs for education and training from software engineers' perspective?*".

We break down RQ into three research sub-questions that guide our data collection:

RQ1: *What are the interests of organisations with an IT division with respect to sustainability?* The sustainability focus depends on the specific business domain and priorities. In this respect, the sustainability perspective depends on their specific interests and stakes. RQ1 helps us define the possible scope of future education programmes.

RQ2: *What do organisations want to achieve with respect to sustainability, and how?* Sustainability can add significant value to both private and public organisations. However, to achieve this aim, sustainability must be tailored and embedded in the DNA of the organisation itself,

[3] In general, with the term "industry" we mean practice from both the private and public sectors.

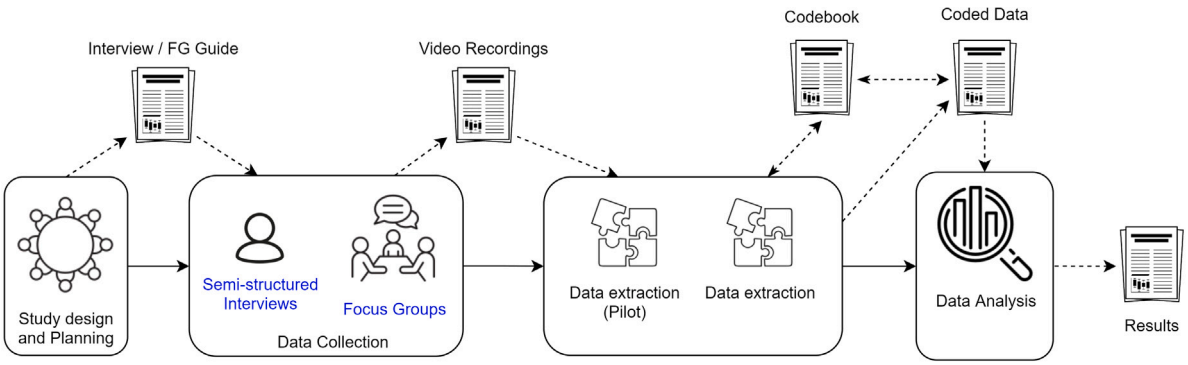

Fig. 1. Study design and execution.

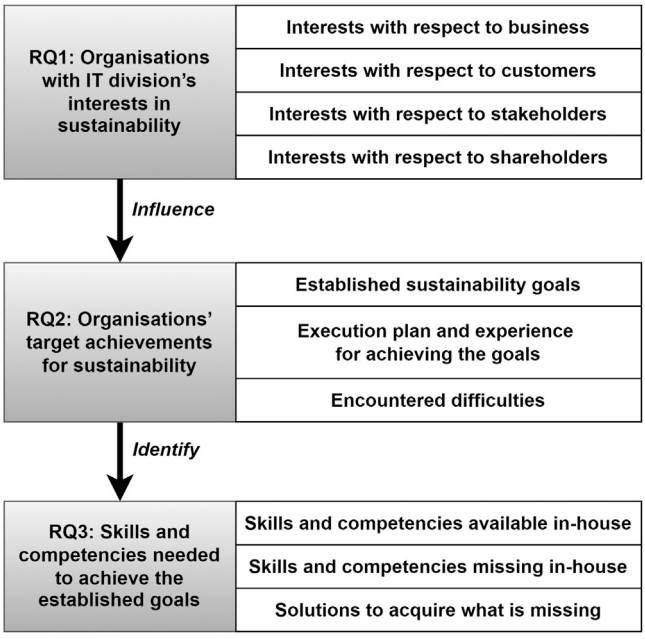

Fig. 2. Themes with respect to research questions.

e.g., its business goals, values, and vision of the future market. Accordingly, this research question investigates the target achievements (what the organisations aim to achieve with respect to sustainability), the influence of software/ICT on these achievements, as well as the difficulties they face and expect. RQ2 helps us define and prioritise the various foci of future education programmes (e.g., creation of innovation, acquisition of new markets, compliance with regulation).

RQ3: *What are the sustainability-related competencies and skills that organisations need to achieve the established sustainability goals?* To different extents, organisations are becoming aware of the sustainability-related competencies and skills that they have already in-house or that they miss in order to achieve their goals. This research question investigates the gaps in the IT workforce and, if applicable, the strategy organisations have in place or envisage to acquire the missing competencies and skills. RQ3 helps us define future education programmes' types and contents (e.g., mono-versus interdisciplinary, higher education versus professional training).

Fig. 2 shows the relationship between RQs and the themes derived from the interviews. In Section 4, we will report in detail the findings related to each theme.

3.2. Data collection and analysis

3.2.1. Data collection

To collect data, we conducted nine individual interviews and seven focus group interviews in a semi-structured format with industry practitioners. Following Kontio et al. (2008), we contacted and recruited the participants by leveraging a mixed-method non-probability sampling, consisting of convenience sampling guided by *ad hoc* quotas (Vehovar et al., 2016). This allowed us to involve participants from different countries and sectors relevant to bringing diverse perspectives related to sustainability needs in practice. In addition to convenience sampling supported by *ad hoc* quotas, we used purposive sampling (Kontio et al., 2008) to further refine the selection of participants. In particular, the participants were required to possess knowledge of both sustainability and the internal operations of the company to which they are affiliated.

Further, we used a mix of individual interviews and focus group interviews to accommodate the schedule of the participants: where possible, we gave priority to focus group interviews to catalyse discussions among the participants; otherwise, we used individual interviews to build upon the familiarity of the researcher and the practitioner in their network. Before starting each session we asked each participant for their consent.

Our selected ICT organisations have supported or participated in sustainability initiatives or have an ICT department involved in sustainability actions as part of the strategy of the company. We selected organisations from different countries and domains, as listed in Table 1, to diversify the perspectives regarding sustainability. The organisations are anonymised to maintain confidentiality. In total, we interviewed 28 experienced IT/sustainability practitioners from 28 distinct organisations in different industrial domains belonging to 9 countries. The study participants were either interviewed individually or in a group.

We followed the statistical classification of economic activities in the European Community (Eurostat, 2016) (NACE Rev 2[4]) to classify the business sectors of the organisations shown in Table 1. Fig. 3 shows the distribution of the sectors according to the NACE Rev 2 statistical classification. To classify the organisation sizes, we followed the (OECD, 2017) scheme. Our participating organisations cover a wide spectrum of areas from software to telecommunications and resource supply. While most of them are private, nearly a third of the organisations (9/28) are from the public sector.

Our participants have significant industry experience and have different roles and positions in their organisations, as shown in Table 2 and summarised in Fig. 4. We strived to have interviewees from all genders participate. The second column shows the business model with respect to the sustainability of their organisations, which is elaborated in more detail in Section 4.1.

[4] https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/ks-ra-07-015.

Table 1
Organisations (anonymised) interviewed per country.

ID	Country	Sector	Type	Size
1	Colombia	Computer programming, consultancy and related activities	Private	<50
2	Finland	Computer programming, consultancy and related activities	Private	50–250
3	Finland	Computer programming, consultancy and related activities	Private	<50
4	Finland	Computer programming, consultancy and related activities	Private	50–250
5	Germany	Computing infrastructure, data processing, hosting, and other information service activities	Public	<50
6	Germany	Computer programming, consultancy and related activities	Private	<50
7	Germany	Computing infrastructure, data processing, hosting, and other information service activities	Private	<50
8	The Netherlands	Computer programming, consultancy and related activities	Private	50–250
9	The Netherlands	Public administration and defence; compulsory social security	Public	250+
10	The Netherlands	Computer programming, consultancy and related activities	Private	250+
11	Norway	Activities of membership organisations	Public	250+
12	Norway	Electricity, gas, steam and air conditioning supply	Public	250+
13	Norway	Land transport and transport via pipelines	Public	250+
14	Norway	Computer programming, consultancy and related activities	Private	250+
15	Norway	Computer programming, consultancy and related activities	Private	<50
16	Norway	Waste collection, recovery and disposal activities	Public	250+
17	Norway	Computer programming, consultancy and related activities	Public	250+
18	Portugal	Computer programming, consultancy and related activities	Public	50-250
19	Portugal	Computer programming, consultancy and related activities	Private	50-250
20	Portugal	Computer programming, consultancy and related activities	Private	<50
21	Portugal	Computer programming, consultancy and related activities	Private	<50
22	Spain	Water collection, treatment and supply	Public	250+
23	Spain	Computer programming, consultancy and related activities	Private	50-250
24	Spain	Land transport and transport via pipelines	Private	250+
25	Sweden	Telecommunication	Private	250+
26	Sweden	Telecommunication	Private	250+
27	The UK	Retail trade	Private	250+
28	The UK	Computing infrastructure, data processing, hosting, and other information service activities	Private	<50

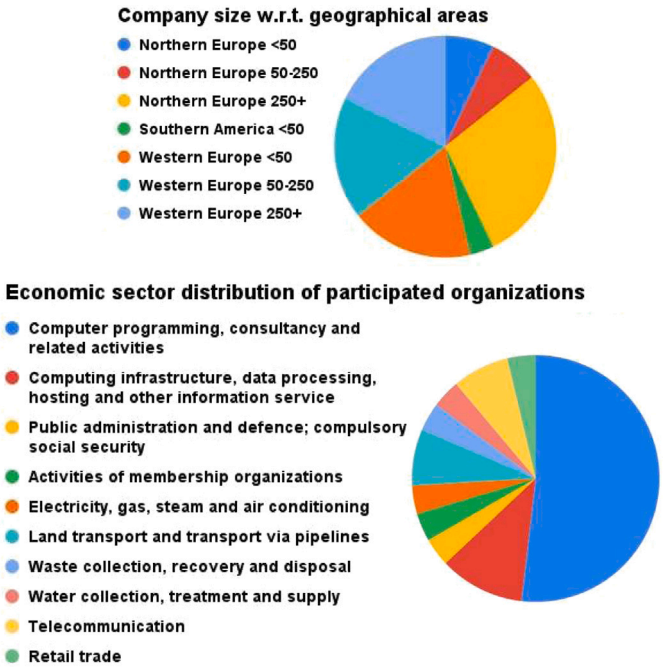

Fig. 3. Distributions of participated organisations w.r.t. size and economic sectors.

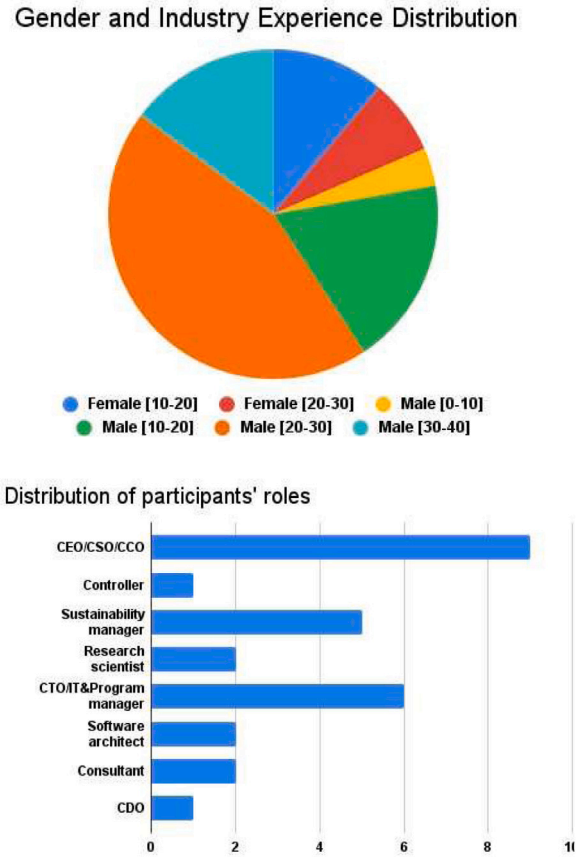

Fig. 4. Demographic distributions of interviewees.

The majority of the participants are seniors with more than ten years of professional experience, and many have a computer science background or degree. We used online teleconferencing tools (e.g. Microsoft Teams, Zoom, Skype) to interview the participants. At the beginning of the interview, we took around five minutes to explain the goals of the interview. The prepared interview questions (see https://bit.ly/390MQju) were then asked one by one. The interviews were conducted from March to September 2021 and recorded with the consent of the interviewees. Individual interviews lasted between 30 min to 2 h, while

Table 2
List of participants per company.

Organisation (Org.) ID	Business model with respect to sustainability	Participant's role	Gender	Age	Years of experience	Years in company
1	Producer	CEO and Consultant	Male	[40–50]	[20–30]	[0–10]
2	Producer	Account manager	Male	[40–50]	[10–20]	[0–10]
3	Producer	Senior advisor (ex. CEO)	Female	[40–50]	[10–20]	[0–10]
4	Producer	Sustainability manager	Male	[50–60]	[20–30]	[0–10]
5	Producer	Principal researcher	Male	[20–30]	[0–10]	[0–10]
6	Producer & Consumer	CEO	Male	[40–50]	[10–20]	[0–10]
7	Consumer	CTO	Male	[30–40]	[10–20]	[0–10]
8	Producer & Consumer	CEO and Solution architect	Male	[40–50]	[20–30]	[10–20]
9	Consumer	Program manager	Male	[50–60]	[20–30]	[0–10]
10	Producer & Consumer	Enterprise architect	Male	[50–60]	[30–40]	[20–30]
11	Producer & Consumer	Director	Female	[30–40]	[10–20]	[0–10]
12	Producer & Consumer	Head of Strategy	Male	[40–50]	[20–30]	[0–10]
13	Producer & Consumer	Head of IT department	Male	[30–40]	[10–20]	[10–20]
14	Producer	Consultant	Male	[30–40]	[20–30]	[0–10]
15	Producer & Consumer	Director and Consultant	Female	[50–60]	[10–20]	[10–20]
16	Producer & Consumer	Chief data officer	Male	[40–50]	[20–30]	[0–10]
17	Producer & Consumer	Enterprise architect	Male	[50–60]	[30–40]	[0–10]
18	Producer	CEO	Male	[50–60]	[20–30]	[20–30]
19	Producer	CEO	Male	[50–60]	[30–40]	[5–10]
20	Producer	CEO	Male	[30–40]	[10–20]	[5–10]
21	Producer	CTO	Male	[50–60]	[20–30]	[5–10]
22	Producer	Environment division chief	Male	[50–60]	[20–30]	[10–20]
23	Consumer	Sustainability manager	Female	[40–50]	[20–30]	[10–20]
24	Producer	Sustainability manager	Female	[30–40]	[10–20]	[0–10]
25	Producer	Principal researcher	Female	[40–50]	[20–30]	[20–30]
26	Producer	Environmental manager	Male	[50–60]	[30–40]	[20–30]
27	Producer	Head of External Collaborations	Male	[40–50]	[20–30]	[0–10]
28	Producer	CTO	Male	[40–50]	[20–30]	[0–10]

focus group interviews took a bit longer time as more discussion arose. The recorded interviews were transcribed manually or automatically by using, e.g., Microsoft Office 365, depending on the researchers' preference. The responsible researchers spent time manually correcting automatic transcription mistakes to ensure the quality of the research.

Finally, for designing the interview sessions themselves, we followed the interview guide approach by Cohen et al. (2017), which helps make explicit the link between research questions, interview questions, and the type of information provided by the answers from the participants. As such, it *"increases the comprehensiveness of the data and makes data collection somewhat systematic for each respondent. Logical gaps in the data [being collected] can be anticipated and closed. Interviews remain fairly conversational and situational"* (Cohen et al., 2017). This both provides more uniformity in the way different moderators carry out the interviews, and helps increase the consistency of the answers.

3.2.2. Data extraction and analysis

To analyse the interviews, we employed the thematic data analysis approach proposed in Vaismoradi et al. (2016). To facilitate the data analysis, we utilised Saturate App,[5] a web-based platform that supports collaborative qualitative analysis. It allows multiple researchers to simultaneously perform activities related to coding, labelling, and categorisation. The data analysis process was carried out as follows: Firstly, the transcripts were imported into the Saturate App. Then, one researcher created the first version of a codebook in an Excel spreadsheet based on the interview questions. During the *data extraction pilot* stage, we performed initial coding for the interview-based data collected from their interviews. They also validated and extended the codebook as needed until it was deemed stable by all coders. Finally, during the *data extraction* stage, ten researchers involved in this study were divided into three sub-groups, each having at least three members. Each sub-group analysed one research question defined in Section 3.1. The groups conducted several workshops to validate and refine the coding done in the first stage so that the original coding for all interviews was verified and agreed on by several researchers.

The codebook has two purposes. Firstly, it formalises what the researchers have analysed from the data during the *data extraction pilot* stage. Secondly, it is used as a guideline in the *data extraction* stage, guiding the researchers who validate and correct the results initiated in the previous step. In the codebook, at the highest level, the coded data were organised according to our three research questions. The main topics are interests, target achievements, and competencies. The codes belonging to these main topics were further organised into three levels depending on their abstraction. The deeper level a code goes, the more detail it represents. Table 3 shows all the codes used. The codebook,[6] with a detailed explanation of each code, is shared as supplemental material to help readers better understand the findings that we report in Section 4 where the codes are highlighted in **bold**. The codebook is organised as follows. Horizontally, it is divided in accordance with the main topics mentioned above (i.e., interests, target achievements, and competencies). The codes belonging to each main topic are vertically distributed into three levels. Each code is accompanied by a definition, a description of when the code is applicable, and a coded text example with the respective source. Table 4 shows sample final results of our data analysis phase, which can also be found in the supplied codebook. The examples contain quotes taken from the interviews and how they are coded during data analysis. The first set of two examples is for RQ1, which helps us identify why sustainability becomes an interest for our interviewed organisations in terms of economic aspects. The second set shows the organisations' goals in relation to sustainability (RQ2). The last set for RQ3 indicates skills that employees of our interviewed organisations possess to help them achieve the established sustainability goals.

4. Results

This section describes the demographics of participants and the findings with regard to our research questions.

[5] http://www.saturateapp.com/.

[6] Codebook access link: https://bit.ly/3wgt0dp.

Table 3
Codes from thematic analysis.

RQ	Level 1	Level 2	Level 3
RQ1	for-business	economic	competition-and-survival, optimisation, efficiency, productivity, resource-utilisation, public-funding, private-funding, business-domain-and-opportunities, regulation, attract-talent, economic-return
		evolution	
		little-or-no-interest	
		technical	technical-concern
		moral	company-values, SDG, environmental-concerns, value-alignment, social-concerns
	for-customers	economic	economic-return, trend-and-funds, economic-concerns, regulation
		moral	value-alignment, environmental-concerns, social-concerns
		little-or-none	
		evolution	
	for-shareholders	economic	market-share, financial-performance, business-opportunities
		evolution	
		societal-concerns	
	for-stakeholders	economic	other-business, policy, regulation, investment,supply-and-value-chain, economic-concerns
		moral	value-alignment, environmental-concerns, societal-concerns
		evolution	
		little-or-none	
		employees	
RQ2	experience	with-external-stakeholders	change-culture, circular-economy, collaboration, mobility, volunteering
		process-within-organisation	automation, carbon-reduction, change-culture, circular-economy, compliance, design, environment, measurement, optimisation, own-workforce, supply-chain
		with-own-product	carbon-reduction, reporting
	goals	with-external-stakeholders	change-culture, regulation, right-decisions, supply-chain
		for-own-process	added-value, change-culture, circular-economy, environment, improve-process, measurement, new-process, own-workforce, right-decisions, understand-to-help-customers
		for-own-product	improve-product, new-product
	steps	with-external-stakeholders	carbon-reduction, collaboration, procurement
		within-own-process	carbon-reduction, certification, collaboration, communication, design, evaluation, implementation, knowledge, measurement, own-workforce, tools
		for-own-product	Planning
	anticipated-external-difficulties	economic	business-model, circular-economy, customer, investors, new-market,
		legal	Regulation
		political	Policy
		social	pandemic, rebound-effect
		technological	Clean-Power
	anticipated-internal-difficulties	people	attract-talent, communication, culture, decision-makers, IT-professionals, understanding
		process	bureaucracy, communication, data-collection, design, financial, measurement, structures, supply-chain, value-thinking
		technology	failure, technical-debt
RQ3	have-in-house	sustainability-skills	clear-vision, some, no-need, tools, circular-economy, waste-management, regulation, environmental-dimension, social-responsibility
		soft-skills	influencing, problem-solving, collaboration, reflection, common-sense
		technical	quality-software, customer/user-centricity, system-thinking, data-management, architecture, compliance, business
	missing-in-house	sustainability-skills	all, multi-disciplinary, general-knowledge, right-talent, environmental-dimension-skills, energy-consumption-awareness, systemic-view
		soft-skills	confidence, stress-management, leadership, communication, ways-of-working, system-thinking, product-management
		technical	data-management, tools, process-understanding, documentation, digital-transformation, metrics
	how-to-acquire-preference	internal-approach	in-house-training, mentorship, events, hiring, existing-experience, predefined-technical-skills, mindset, communication, integration
		external-approach	university, external-course, consultancy, community, through-collaboration, through-partnership, through-tools

Table 4
Example results of data analysis.

Id org.	Quote	RQ	Code
3	"*Young people want to join us because they want to work for technologies that are basically improving sustainability.*"	RQ1	for-business/economical/attract-talents
27	"*If we have skills to optimise our algorithms to reduce our cloud costs, it is a financial benefit for us.*	RQ1	for-business/economical/economic-return
1	"*When you see the flow of value and start identifying where waste goes, you can deliver a better and cleaner system.*"	RQ2	goals/own-process/understand-to-help-customers
18	"*We are seeing IT more as a means to get insights on how to create sustainability, to be able to steer the effects and decisions you make.*"	RQ2	goals/for-own-process/add-value
2	"*We have talents with long backgrounds in software development and good knowledge of building top-quality software.* "	RQ3	have-in-house/technical/quality software
15	"*We have a lot of employees who are educated in IT. They are also business advisors.*'	RQ3	have-in-house/technical/business

4.1. Demographics: role with respect to sustainability

In this section, we report the demographics concerning the business visions of our interviewed organisations and their perceptions of sustainability.

4.1.1. Organisations' role with respect to sustainability

We classified our interviewed organisations as producers or consumers (or both) of sustainability solutions in IT. The *producers* were the organisations that produced tools or software solutions to support sustainability initiatives. The organisations that use these products were classified as *consumers*. Some organisations played both roles. The "Business model with respect to sustainability" column of Table 2 shows the classifications of the organisations who used one of these models or both. While the majority of our interviewed organisations (n = 16), from nine different countries were solely producers, only a few (n = 3) from three countries were solely consumers. Some organisations (n = 9) from three countries played both roles. Finally, part of the organisations (n = 9) operate in the public sector, while the rest are private organisations.

In our sample, many organisations produced sustainability solutions in-house rather than relying on other organisations. As explained above, these are tools or software solutions to support sustainability initiatives. In many cases, the sector to which a company belonged did not impact the role adopted. Furthermore, the producer role was more common in software and technology organisations. Therefore, we can see that digitalisation plays a key role in providing consumers with sustainable solutions. Finally, we observed that organisations adopting both roles belonged to the public sector (e.g., energy, water management) acting as end-users that demanded sustainable solutions but also developed sustainability solutions in their IT department that were used by the environmental department.

4.1.2. Organisations' perception of sustainability

We did extract the organisations' perceptions of sustainability that exploratively emerged when analysing the qualitative data. Overall, the main focus of organisations when discussing sustainability was on the environmental dimension. For many organisations (n = 10), their statements could be interpreted as that they perceived sustainability as environmental issues such as carbon emissions, climate change, and energy consumption.

Some organisations (n = 8) did also mention the economic dimension as part of sustainability. From these, a few organisations (n = 3) referred to the financial impact of their products on their businesses ("*[...] whenever we are making the systems, especially architectural or technological decisions, we consider the economical impact a lot*" – Org. 2) and also talked about economic sustainability in the sense of circular economy. The social and technical dimensions were considered part of sustainability by part of the organisations (n = 7). For the social dimension, the focus was on their own workforce (e.g., providing yoga classes), the customer (e.g., improving customer satisfaction), and society (e.g., fighting against poverty) as a whole. For the technical dimension, the interviewees' statements suggested that sustainability was related to a quality attribute of IT products and services, such as reusability, robustness, security, etc. Finally, a number of organisations (n = 12) explicitly considered sustainability as related to more than one dimension and, surprisingly, only a small fraction (n = 4) mentioned the SDGs as relevant to them. In conclusion, we observed that a prominent focus of organisations when discussing sustainability was on the environment. Economic, technical, and social issues were also popular topics.

4.2. RQ1: what are the interests of organisations with an IT division with respect to sustainability?

For this RQ we asked the organisations about their interests in sustainability from four perspectives: their business, their customers, their shareholders, and their stakeholders.

4.2.1. Interests with respect to business

When discussing the reason why sustainability was interesting for their **business**, it was not surprising to observe that economic reasons played an important role and were followed by moral and social matters.

With regard to **economic** reasons, sustainability helped our interviewed organisations to open new business opportunities, to their competitiveness, to have license operate, to reduce costs, and to acquire and retain talent more easily. In particular, many organisations (n = 16) affirmed an interest in sustainability because it created new **business opportunities** or helped to mitigate potential threats. Overall, our interviewed organisations had one of the following three profiles: sustainability was their main business (e.g. they offered solutions for circular economy or sustainability reporting), they were in an industry that is being highly impacted by sustainability demands (e.g. mobility), or their customers were demanding it. Part of the organisations (n = 9) viewed sustainability as a matter of **competitiveness and survival**. While some used sustainability to differentiate themselves from competitors, others were aware that different organisations were investing in sustainability-related initiatives and did not want to be left behind. For example, Org. 6 stated that "*[sustainability] is another point of differentiation*" and Org. 23 mentioned that "*all the organisations that are emerging and that are effectively working, are those that have that sustainable consistency at an environmental and social level*". Finally, for some organisations, it is a matter of making sure that they would continue to **utilise the resources** they needed to function; for example, Org. 22 is fighting climate change because "*we are going to stop having the main resource of our factory, which is the water*". Few organisations (n = 3) explicitly stated that implementing sustainable practices brought them **economic advances**. Org. 27, for example, had a predictive algorithm for product demand that helped its clients to minimise food waste and sought to optimise its algorithms to reduce cloud and energy costs. For a fraction of the organisations (n = 6), sustainable practices were adopted to comply (or help others to comply) with **regulations**. Org. 22, for example, shared that *"everything to do with climate- and environmental policies have become structural"*. Finally, a small group of organisations (n = 3) saw that sustainability was vital to **attracting talent**. These organisations felt that highly skilled professionals wanted to work for firms where they shared their values and put time and effort into something meaningful.

Sustainability was also related to **moral** concerns. Part of the organisations (n = 8) invested in sustainability because they truly believed in it, sometimes being directly **aligning to the company's values**. Two illustrations of this belief were *"our goal as a company has been focused on providing something to society and not just doing profit"* (Org. 18) and *"our mission or reason for existence is that our business is coming from sustainability"* (Org. 3).

Unsurprisingly, when talking about their interest in sustainability, **environmental** concerns such as reduction of waste, water and energy use, and carbon emissions were the most present (n = 15). These concerns were related to both the purpose and the operation of the business. Finally, a handful of organisations (n = 4) explicitly stated that sustainability (or specific dimensions of it) was **not of concern** to them. For example, ecological sustainability was *"almost the last perspective for us in daily life"* (Org. 2).

4.2.2. Interests with respect to customers

Differently from the business perspective (mainly focused on the economics), the **customers** of our interviewed organisations were reported to be most attracted to sustainability by moral values. In particular, they aligned their businesses to sustainability due to ecological and societal concerns. Economics, e.g., business opportunities returns, was the second most popular reason for investments. Here it is worth highlighting that several of the interviewed organisations adopted a business-to-business model, therefore, their customers were other organisations rather than individuals.

Among the **moral** reasons driving our interviewed organisations' customers to sustainability, many organisations (n = 16) shared that their customers wanted to **protect the environment** by reducing carbon emissions and electricity use. At the same time, **social matters** were of concern to other organisations (n = 9). Especially, COVID-19 was the most frequently mentioned issue as the pandemic forced organisations to adapt their businesses for survival. For example, Org. 23 shared that most products requested by its customers in the previous two years from the interview were related to the pandemic. In addition, a few organisations (n = 4) viewed **value-alignment** as another reason for customers' interest in sustainability because this was an important concept in society.

Regarding **economic** aspects, **investment returns** and **business opportunities** were the two most popular reasons. A small portion of organisations (n = 3) mentioned that sustainability was a core business value of their customers: "*Sustainability and circular economy are [our customer]'s core business*". (Org. 3). At the same time, the focus on sustainability had **evolved**, so our interviewed organisations and their customers had to proactively adapt their businesses to the new trends.

Interestingly, a few organisations (n = 7) mentioned that despite having an interest in sustainability and in products addressing sustainability-related aspects, they still struggled to win customers due to **no interest**. Org. 21, for example, admitted that "*I'd love to design more services for sustainability, but I don't get any requests, and I really struggle to sell it*".

4.2.3. Interests with respect to shareholders

The interest with respect to **shareholders** (n = 13) seemed less important than the interest with respect to business and customers. In particular, there were mentions of economic interests (n = 9) followed by societal concerns (n = 4). A few organisations (n = 3) mentioned that the interest of their shareholders in sustainability had changed over time. The **economic** interest was what organisations saw as important for their shareholders. They mainly argued that their shareholders considered sustainability as a **business opportunity** to increase their financial performance and their market share. See, e.g., Org. 24: "*If we don't adapt the business and create new KPIs and processes related to sustainability, the risk is high for the shareholders because we can lose some parts of the market*".

A handful of organisations (n = 4) did consider **societal** concerns as an important aspect for their shareholders. Org. 18 stated: "*[shareholders] have a vision not just of making a profit but as a vision of contributing to a better society (...)*". Additionally, the interviewees stated that the shareholders' interest in sustainability **evolves** due to compliance constraints (e.g., EU taxonomy for sustainable activities — https://bit.ly/3xYpBAF) and societal concerns (e.g., social responsibility).

4.2.4. Interests with respect to stakeholders

The responses from the organisations showed that sustainability interest from **stakeholders** was highly influenced by media news on sustainability, especially regarding **environmental concerns** like reducing emissions and fighting climate change: "*(...) if you take into account the ecological point of view, you'll have less* CO_2" (Org. 7). There were also several drivers for the **evolution** of stakeholders' interests in sustainability, such as the United Nations Framework Convention on Climate Change (UNFCCC), which launched the Race to Zero campaign and influenced several organisations working towards sustainability. A few organisations (n = 3) were working on building an ecosystem with partners who shared the same sustainability values, because sustainability **value-alignment** was an important element for their stakeholders.

In addition, **employees** were key stakeholders who drove sustainability interest within organisations (n = 6) because they wanted to feel a sense of contributing positively towards sustainability: "*They are aware of the sustainability issues, and they want to have a positive impact on these issues*". (Org. 18). Also, organisations wanted to create employee satisfaction through different aspects of sustainability to attract talent based on the company's identity and activities towards sustainability. In addition, for some organisations (n = 8), stakeholders' interests revolved around **societal concerns**, such as human rights, as well as individuals taking action and being accountable for their activities towards sustainability.

RQ1 summary

Interests with respect to business:
The interviewees highlighted that the economic benefit brought by sustainability was the main driving force for the organisations' interest. However, only a small number of organisations specifically stated that implementing sustainable practices brought them economic gains. The advantages explicitly mentioned are to be found in the area of business opportunities and competitiveness. Concerns about environmental impacts were also very present.

Interests with respect to customers:
Interviewed organisations felt that their customers had moral concerns that they had to respond to. The most mentioned moral concerns driving customers, according to our interviewees, are environmental ones, specifically reducing carbon emissions and energy use as well as social matters. With regard to social concerns here, COVID-19 had a strong impact on the customer's demands. Despite these demands, several organisations mentioned that they had difficulties to win customers due to a lack of interest in sustainability.

Interests with respect to shareholders:
Economic benefits, especially business opportunities, were what the organisations saw as most important for their shareholders. Aside from that, some organisations did mention social concerns as an important aspect for shareholders.

Interests with respect to stakeholders:
External drivers such as the media and the development of international frameworks highly influenced the interest of stakeholders in the sustainability of the organisations. Another main driver was employees' personal interest.

4.3. RQ2: what do organisations want to achieve with respect to sustainability, and how?

To answer this RQ, we asked the organisations about what they wanted to achieve with sustainability in their business, how their ICT products/services supported achieving these goals, and what difficulties they faced, or expect to face, in achieving these goals.

4.3.1. Established sustainability goals

The sustainability **goals** of the interviewed organisations focused primarily on their processes, followed by their need to create or improve their products, and finally on the external factors impacting their goals. Interestingly, social goals (e.g., human rights, and inclusion) were not their top priority at the moment. RQ1 findings showed that the organisations and their customers had shown a strong interest in social issues when referring to sustainability. Particularly, social matters were the second highest interest of our organisations and of their customers. However, these aspects were not taken into account when organisations defined sustainability goals. It indicates that although social matters were good reasons to draw organisations' attention to sustainability, they still did not create viable opportunities for them to set related business goals.

In relation to the internal working **process**, organisations (n = 14) highlighted how **process improvement** had contributed to addressing their sustainability goals, including automation and optimisation. For

example, Org. 1 highlighted the importance of values and mindset: "*shift [our business partners]'s mind to the value mindset from the project mindset.*" A few organisations (n = 5) stressed the importance of **collaboration and leading by example** to inspire, influence, and motivate others to follow their lead. Others (n = 6) reflected on their personal and professional decisions motivated by internal organisational and personal values to identify opportunities and take responsibility in relation to what motivated and positively influenced their **decision-making process**. Org. 18 stressed that as a company, they *"have always had the goal of having a positive contribution to society as a whole"*. A handful of organisations (n = 4) commented that the organisational environment, belief, awareness, and communication linked to values were critical to **changing culture**. However, this needed to *"be accompanied by a sustainable pace"* (Org. 1). A few organisations (n = 3) had introduced **new processes** to address sustainability internally but wondered how they could optimise their processes.

Concerning the organisations' planned **products**, several (n = 7) highlighted opportunities to develop **new products** to create new markets. For example, the core business of Org. 15 was reviewing their clients' products in order to suggest new sustainable business strategies: "*We try to take a position in the market not as a regular IT supplier but more as a partner. We [and our customers] aimed not only to make financial benefits but also benefit the environment and the social side.*" Organisations (n = 5) highlighted how they were improving product quality for both their clients and their organisation by demonstrating how sustainability could be integrated as a core element. When clients lacked the required knowledge or expertise, these organisations were able to provide models and examples of good practice.

Finally, regarding the **external** factors affecting the company goals, a few organisations (n = 3) discussed the importance of their customers making the **right decision** for the larger community and global sustainability. Org. 2 even took this as far as challenging the need for a customer's development proposal, resulting in business loss when the potential customer decided to cancel the project. Also, organisations (n = 3) highlighted the importance of looking beyond the boundary of the company to engage with sustainability in their **supply chains**. Org. 23 emphasised that "*we are going to review our supplier code of ethics. We want our suppliers to sign it and take responsibility because if we do it well, we have to go hand in hand with people who do it well.*" However, they pondered how to achieve this, and needed tools to help them in making the right decisions.

4.3.2. Plan and experience for achieving the goals

This section presents findings on executing sustainability goals and reported experiences.

4.3.2.1. Plan. Among the **steps** to achieved the established sustainability goals, organisations mentioned actions related to external factors with an impact on their goals, as well as the changes required to their internal process and product.

With regard to **external** factors, the most cited concern was seeking **collaboration**. Some organisations (n = 7) prized collaborations with external entities (e.g., clients, municipalities, NGOs, and universities) and international alliances to push their limits, making them more ambitious in their goals. The UN Global Compact[7] was acknowledged as a good way to create synergies, gain strength, and be inspired by the work of others. The interviewed organisations also held thorough discussions on internal **process** transformation, focusing first on process design, second on tools, certification, and measurement, and third on implementation, evaluation, and internal collaboration.

The **design** of sustainability processes was cited by a few organisations (n = 5) that use agile and incremental improvements, the ABCD process,[8] and the SSD framework. Org. 1, advocating for agile approaches, highlighted the importance of seeing a system as a matrix connecting its different parts to be aware of the effects of a given action on the system's value chain. A handful of organisations (n = 4) highlighted the need for **tools** for sustainable systems. The tools mentioned were Care to Create, a flourishing business canvas to capture economic and social value, SSD framework for strategic sustainable development, and software for environmental accounting. Other organisations (n = 4) discussed **certification**, sharing their uncertainties and concerns on measurement processes to achieve sustainability, particularly related to the lack of consistent methodologies to implement it. Organisations also referred to BREEAM and B Corp (n = 2) and the importance of all types of certifications they adopted to prevent anti-corruption and comply with data protection (n = 1). Another company reported having their Environmental programme approved and a Social Responsibility programme already drafted. Also, crucial to some organisations (n = 4) were the **measurement** processes to achieve sustainability, and related to this was the lack of consistent methodologies to implement such measurements, as stated by (Org. 10) *"there's not a formal training program on how to develop sustainable solutions (...). [there's no] consistent methodology that guidelines how to implement it. (...) it will come to be certain because we're in a highly regulated company"*. Org. 17 used BREEAM and other certifications to measure and track the achievement of their goals.

A few organisations (n = 3) mentioned the importance of process **evaluation**, either by setting clear objectives (e.g., becoming CO_2 neutral), implementing and testing them or by defining end-to-end sustainable propositions to make contributions to the community. Org. 1 also complained that when a company is in financial trouble, the quickest decision is firing people instead of analysing the system and thinking of a way to add value to it. They called for a change of mentality where employees do not simply follow instructions but are able to raise their concerns.

Lastly, organisations (n = 3) proposed different ways to work in **collaboration** with their clients and partners to promote sustainability, from organising workshops to joining Global Compact and offering their clients solutions with extra sustainability features.

4.3.2.2. Experience. While achieving sustainability goals, the organisations collaborated with external business partners and reformed the internal organisation. Among the adopted actions, reducing energy consumption and cutting carbon emissions were the two most mentioned.

Regarding **external** factors, a few organisations (n = 3) reported that they sought **collaboration** with business partners to bridge the sustainability gaps within their organisations. Asking for training to enrich the workforce's knowledge about sustainability and raise clients' awareness of sustainability was one of the most popular choices: "*We have organised some workshops with an environmental expert and also invited clients to speak precisely about the importance of sustainability.*" (Org. 23). Another solution was to purchase the services the organisations needed to achieve their sustainability goals. For example, Org. 11 shared that they were working with a software consultancy company to produce a reporting toolbox tracking the amount of carbon emitted by its systems.

Regarding **internal** reform, organisations adopted different solutions, such as **reducing carbon footprint** (n = 7) and employing software technology to **automate** the working process (n = 3). To reduce carbon emissions, Org. 23 was particularly proud of its involvement in reforestation efforts to offset its carbon footprint. Org. 4 provided bicycles for staff and encouraged cycling to work; the initiative received high appreciation from its employees and media.

[7] https://unglobalcompact.org.

[8] ABCD is part of the Framework for Strategic Sustainable Development (SSD). Source: https://www.naturalstep.ca/abcd.

Regarding automation, Org. 28 stated: "*Test automation helps build sustainable software because you have confidence that a particular unit operates in a certain way.*" Some organisations (n = 5) re-**designed** their internal working processes in several ways to align themselves with the established sustainability goals. See the recommended procedure of Org. 1: "*So the first part is to identify value, to take care of value. Once you see that, you start changing things with little experiments.*" Organisations (n = 3) also reported their internal **culture** coincidentally changed on the journey to accomplish the goals. Org. 25 stated that aiming for sustainability goals initially created more work and caused objections, but over time, the passion has been growing among the staff in several departments.

Finally, for those who sell **products** related to sustainability, such as power-saving utilities and carbon emission reporting software, organisations (n = 3) mentioned that they invested in new infrastructure to **reduce energy consumption**. In particular, Org. 24 stated: "*We sell different products and services that help reduce emissions.*"

4.3.3. Encountered difficulties

The difficulties in achieving the established sustainability goals are categorised into external and internal. More internal difficulties were reported.

4.3.3.1. External difficulties. Economic barriers were the most frequently mentioned, followed by policy issues.

Regarding **economic** barriers, a few organisations (n = 4) emphasised the difficulty in finding **customers** willing to pay for more sustainable products or services. Org. 19 specifically mentioned that customers' procurement teams were "*only focused on price*" and they had to sell the ideas to other decision-makers outside of procurement. Org. 16 aimed to be an enabler for the **circular economy**, but was hindered by a lack of consistent models from other organisations. The economic barriers were not just in relation to customers; another company reflected on the difficulty of securing **investors**, who were focused on rapid growth and scaling up.

Policy issues were highlighted for not creating the conditions for sustainable products and services to compete. Policymakers represented a key difficulty (n = 5). Organisations struggled to compete against less sustainable alternative suppliers when the policy context did not require or incentivise sustainability improvements in products and services. Several organisations identified a gap between the aspirations politicians stated and the **regulations** in force. Org. 9 felt this might be due to politicians' lack of understanding of digitalisation, who then "*proposed unreasonable laws*". The impact of these policy failures was reflected in the second most serious concern, that customers were not prepared to pay more for these sustainable products and services. A few organisations (n = 4) cited external **technological** barriers, such as a lack of charging infrastructure for electric vehicles.

4.3.3.2. Internal difficulties. People (n = 25) and processes (n = 23) are overwhelmingly represented in the organisations' answers, while technologies (n = 2) are barely mentioned. It shows that non-technological difficulties were prevalent in our sample.

Regarding **people** barriers, organisations (n = 14) pointed out the lack of **understanding** of sustainability concepts as one of their most significant challenges. This may be due to the extent and vagueness of the concepts themselves and the insufficient knowledge of their employees. Some further explained that the complex conceptualisation of sustainability at a company level also made searching for sustainability skills in new potential employees a challenging task, as the existing workforce was not qualified to assess the needed skills or their fulfilment by applicants. Org. 4, for example, stated: "*Terminology/concept is still vague, especially what kind of skills and competencies you already have in-house*". Furthermore, organisations (n = 10) identified the **culture** of their employees, its complexity and inertia, as one of the important internal challenges. Org. 25 stated that "*We had many key stakeholders and people at the bottom. We had some commitment on the high management, but it didn't connect because it was blocked in sub-optimisations of middle management who try optimising their own budget or their own question*". The culture was often oriented toward different KPIs (Key Performance Indicators) and conflicts with sustainability goals. The short-term priorities and missing skills of **decision-makers** were also (n = 7). Org. 18 noted: "*managers usually have more short-term goals and it's not easy to sell them a long-term plan that won't give profits to the company for years*".

With regard to difficulties arising from the internal working **process**, we found a **financial** trade-off between short-term financial profitability and long-term sustainability goals one of the most frequently mentioned difficulties (n = 15). The issue occurred in both our interviewed organisations and their customers. Organisations (n = 9) encountered an issue regarding the ability to carry out sustainability-relevant **measurements**. For example, Org. 9 admitted that "*[their employees] don't know how to measure sustainability, or how to advance the policy agenda on sustainability using IT or digitalisation*". Org. 4 highlighted the challenges to calculate the CO_2 footprint of cloud services.

At first sight, these external economic barriers and internal short-term financial gains may seem to contradict the results of RQ1, which stated that the economic benefits brought by sustainability were the main driving force for the organisations' interest in it. This is a common conflict. Sustainability demands long-term investment. However, it can be difficult to convince internal and external stakeholders to sacrifice fast economic growth in favour of the long-term economic benefits brought by sustainability.

RQ2 summary

Established sustainability goals:
The interviewed organisations highlighted the need for improving their design processes and products to support sustainability and stressed the importance of a change in culture to positively contribute to society and help their customers make the right decisions.

Execution plan and experience to achieve the goals:
To achieve the established sustainability goals, the organisations focused on seeking collaboration with their business partners and other external entities, transforming their internal working processes, and developing tools to support interconnectivity, interdependence, and adaptability. The experiences reported included knowing how to collaborate with external stakeholders effectively, reducing carbon emissions, and applying automation when possible.

Encountered difficulties:
The difficulties reported were caused by internal and external factors. The major internal factors were related to the trade-off between short-term financial profitability and long-term sustainability goals, an unclear understanding of sustainability concepts and goals, and the culture of the employees, which was often oriented towards KPIs in conflict with sustainability goals. With regard to external factors, economic barriers and inadequate policies were the two most frequently mentioned.

4.4. RQ3: "What are the sustainability-related competencies and skills that organisations need to achieve the established sustainability goals? "

To answer this RQ, we asked the respondents about the skills and competencies available and missing within their organisations, as well as their approaches to acquiring those identified as lacking. In our context, skills are the specific learned abilities needed to perform a given job well. On the other hand, competencies are the person's knowledge and behaviours that lead them to be successful in a job.

4.4.1. Skills and competencies available in-house

From the interview data, we observed that there was a wide variety of skills and competencies required by our interviewed organisations to achieve their established sustainability goals. Only a subset of the skills and competencies were claimed to be available in our respondents' organisations, but not all. In addition, the sets of available skills and competencies were not the same among the organisations.

These skills and competencies were categorised into sustainability-related skills (e.g., organisations stated that they had knowledge of the sustainability-related regulations in their domain), soft skills (e.g., organisations saw that they had good problem-solving skills in sustainability challenges), and technical skills (e.g., organisations saw they had the ability to create technically sustainable solutions).

There are were different perspectives on **sustainability-related** skills. The organisations either thought about sustainability in a holistic, higher-level manner or focused on some specific details of sustainability. From a high-level perspective, many of our interviewed organisations believed that sustainability knowledge was not that important for IT staff. In particular, organisations (n = 7) thought that IT staff did **not need** to acquire sustainability knowledge, and other (n = 7) required **little background** from their employees. These organisations did not mean that they did not emphasise sustainability, but they distinguished IT people from sustainability experts. When the organisations focused on specific sustainability-related skills, they mentioned different sustainability dimensions, application domains, and tools and approaches to achieve them. The organisations seemed to have an understanding of both **social** and **environmental** dimensions: "*[Our staff] have the environmental knowledge and have involved in GRI*[9] *and CDP.*[10] *They can use these competencies to help our customers*" (Org. 14). These dimensions also linked closely to the **regulations** that the organisations had to obey, as mentioned by Org. 14: "*we've been working with our customers and see how EU regulations have evolved*".

The organisations indicated several **soft skills** they thought were valuable while aiming for sustainable solutions. Some of these skills were rather traditional, like **problem-solving** and **collaboration**, while others, such as **common-sense**, **reflection and influencing** related to the aim for effects on sustainability. The problem-solving and collaboration skills are closely linked to the sustainability-related skills presented above. The most referenced (n = 7) category of soft skills was **influencing**. It shows how organisations recognised their skills to influence the customer and the outcomes. For example, Org. 2 mentioned, "*...their daily work has influenced customers' teams about what should be done*".

The last set of skills that the organisations sought to have in-house was of a **technical** nature. Most of the categories link with IT-related skills and were clearly stated by our interviewed organisations, for example, **software quality**, **user-centricity accessibility**, **architecture**, **data management**, and **systems thinking** skills. While the first four skills were more familiar to the ICT community, the meaning of the systems thinking skill explained by Org. 18: "*we are software engineers, so systems are quite familiar to us. We know the different parts of it, how they interact, and how they join together.*" Surprisingly, organisations (n = 5) emphasised most the business skills they have in-house and considered part of the technical skillset, as highlighted by Org. 15: "*Most of our developers are also business advisors. We are now adding more competent business advisors having an IT background.*"

4.4.2. Skills and competencies missing in-house

Similar to the analysis for skills and competencies available in-house, in this section, we cluster the missing skills and competencies into three categories: sustainability-related skills and competencies, soft skills, and technical skills.

With regard to **sustainability-related skills and competencies**, our interviewed organisations mentioned that they lacked many of them, such as the right talent with knowledge of sustainability and the ability to transfer that to new IT business opportunities, the IT staff who were both excellent at technical skills and sustainability knowledge, and the talented programmers who could deliver energy-efficient code. In particular, organisations (n = 6) recognised the importance of sustainability knowledge but faced difficulties in hiring the **right talent** with suitable sustainability-related skills. Some organisations (n = 5) mentioned that their staff lacked a **multi-disciplinary** skill set. For example, Org. 18 expected their IT staff to have some sustainability knowledge and stated that "*...would be good if we can have some of those professionals that could combine sustainability and good background on ICT.*" A few organisations (n = 3) wanted their IT systems to be **energy-efficient** and **environment-friendly** but did not have developers who had these relevant programming skills.

Regarding missing **soft skills** that are crucial for organisations with respect to sustainability, communication, and systemic thinking were frequently mentioned. Particularly, poor **communication** skill was an issue experienced by some organisations (n = 4). This was visible for the people who worked directly with customers (e.g., the marketing department): "*We have been facing the challenges that we think that we have the perfect idea that the customer would benefit from, but we are having difficulties selling that to the customers.*" (Org. 4). The company also experienced that communication was ineffective among its IT staff. **Systemic thinking** was an ability to have a holistic view of factors and interactions that could contribute to a better possible outcome. However, a few organisations (n = 3) mentioned that they could not identify this competence in their IT workforce. Org. 17 stated that "*if we had a framework or skills on how to put it all together in the bigger picture, we could have optimised our solutions for the entire system, not just specific code segments, or applications*".

Software engineering is a technological field, but our respondents mentioned several missing **technical skills**. Specifically, organisations (n = 6) reported the lack of **metrics** to measure the impact of their IT products on sustainability. For instance, Org. 2 stated: "*We don't have good means to measure the sustainability level of certain software entities or our customers.*" Data has been increasingly collected in recent years, but a few organisations (n = 3) did not equip themselves well with **data management** skills. These organisations faced some difficulties in complying with GDPR (General Data Protection Regulation) in terms of data handling.

4.4.3. Solutions to acquire what is missing

Based on the identified skills and competencies missing in-house, we further investigated how the organisations were acquiring them. Overall, the acquisition strategies can be classified into two types: internal (i.e., carried out within the company) or external (i.e., when the skills and competencies are provided from a source external to the company).

In relation to the **internal** approaches, the most common (n = 20), unsurprisingly, was by providing and/or organising **in-house training**: "*...what we do to make the change in the organisation, I think we do both retraining and changing the behaviour in the organisation itself*" (Org. 10). **Hiring** was also a widespread internal strategy (n = 13). Organisations used recruiting as an instrument to bring in new employees with suitable sustainability-related skills and competencies. This process also involved internal training in order to adapt newcomers to the organisation's culture and working process. There were several hiring targets being adopted by the interviewed organisations, including looking for specific pre-defined competencies (e.g., "*We hire people that have some*

[9] GRI: an international independent standards organisation that helps businesses, governments and other organisations understand and communicate impacts on issues like climate change, human rights, and corruption.

[10] CDP: an international non-profit organisation that helps organisations and cities disclose their environmental impact.

specific set of skills and also have a passion or interest in sustainability" - Org. 20), people with the right mindset for the organisations. In addition, to address the communication issues, new hires were expected to "*...establish and maintain good discussions with customers and stakeholders*" (Org. 2). Establishing **mentorship** programmes that engage experienced employees in sharing their own experience, knowledge, and know-how with other staff members; and conducting **internal events** for knowledge sharing were two other solutions mentioned by two organisations.

When it comes to **external** approaches, collaborating with universities, sending employees to participate in courses about sustainability, and hiring consultants were popular solutions. Firstly, we found that a significant number of organisations (n = 11) expected to acquire the missing competencies either via new hires contributing the right background from their **university** education or by means of research collaborations with universities. For example, Org. 7 stated: "*To get this knowledge into our own company, we really need research or try to get information from universities*". Secondly, a few organisations (n = 4) frequently paid for **external courses** to train their own workforce. This strategy assumed that either suitable courses were available or external training organisations offered customisable course packages. Lastly, organisations (n = 4) preferred to hire **consultants** on sustainability when sustainability-related competencies or skills were needed: "*For externally-reused software, cloud services, or to address specific sustainability goals, [...] we would partner up with somebody or buy consultancy hours*" (Org. 16). This was another external strategy when missing competencies and skills were acquired temporarily and typically for a specific project.

RQ3 summary

Skills and competencies available in-house:
To reduce the expectation level for the staff, many organisations separated IT departments from sustainability experts, so a sustainability background was not normally required for IT-skilled employees. However, specific soft skills (e.g., problem-solving, collaboration) and technical competencies (e.g., architecture, data management) were expected and available within the IT workforce to achieve the target sustainability goals.

Skills and competencies missing in-house:
Despite separating IT departments from sustainability experts to reduce the need for sustainability knowledge, many organisations still wanted to fill that gap for their IT staff. Improving communication efficiency and defining sustainability measurement metrics were often mentioned as missing soft and technical skills within the organisations' workforces.

Solutions to acquire the missing skills and competencies:
The organisations took both internal and external approaches to fill sustainability knowledge gaps for their IT staff. Popular solutions were organising in-house training courses, collaborating with universities, sending employees to externally organised courses, and hiring sustainability consultants.

5. Interpretation of results

This section discusses the skills gaps apparent from our results and that future education programs should address.

(On RQ1) Interests in sustainability are diverse and evolving. Currently, professionals are not able to understand and relate multiple aspects of sustainability and translate these relations into concrete business when needed. Educational programmes should enable this competency while being flexible and ready for changes.

Our data show that economics is the main driver for our interviewed organisations and their shareholders to invest in sustainability. This

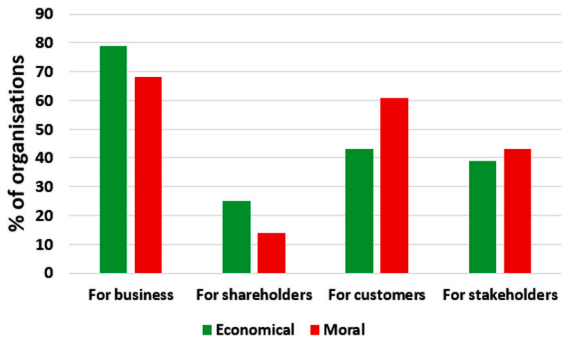

Fig. 5. Reasons for the interest in sustainability.

is not surprising since they must survive in the market. However, as shown in Fig. 5, there is pressure from customers and stakeholders to push for social and environmental sustainability impacts. So, one must try to turn these aspects into economic profit; therefore, ideally, one must change the value proposition. The business vision of an organisation must be decided based on multiple factors, its own business', customers', shareholders', and stakeholders' interests. As such, to prepare a better workforce for IT organisations, future educational programmes should help professionals relate concerns belonging to different sustainability dimensions and be able to translate such relations into concrete business plans. This means that IT professionals need to understand better what drives the businesses they work for, the opportunities that focus on sustainability open to businesses in general, and the threats faced by businesses causing harm to the environment and society. Understanding this might help them to champion the idea of sustainability internally and justify it in terms of economic, environmental, and societal reasons.

Around 40% of the organisations mentioned that their interests in sustainability evolved due to new demands from customers and regulations. Such evolution might pose difficulties to organisations, so future educational programmes should be flexible and ready to adapt to changes. At the same time, 14% of the organisations are not yet concerned with sustainability. In this case, education plays a role in creating awareness within businesses about the relevance and opportunities of sustainability within IT, accelerating the IT industry's interest in sustainability.

From the data, we identify that around 10% of IT organisations are interested in sustainability but do not know how to take it into account. Educational programmes and specific industry training can help.

(On RQ2) The IT workforce needs sustainability-related competencies and a deeper understanding of how sustainability impacts development processes and resulting products. Educational programmes should provide them with tools to develop sustainability-aware systems and inspire others across their network of collaborating organisations to embrace sustainability initiatives.

Sustainability is activating organisations to change internally (e.g., how development and decision-making processes are revisited to address sustainability goals) and externally (e.g., how organisations offer their customers new or improved products and services with respect to sustainability). At the same time, organisations encounter a number of difficulties (further analysed below) that designers of future educational programmes for IT students should take into account when making improvements.

As summarised in Fig. 6, lack of funds and sustainability understanding, as well as the need to change the internal culture to favour sustainability more, were the three major internal difficulties reported by the organisations. Financial challenges may force organisations to downgrade sustainability objectives to survive, even though sustainability is something most of them want. This shows a need to create more value for sustainability-aware software products, and this may

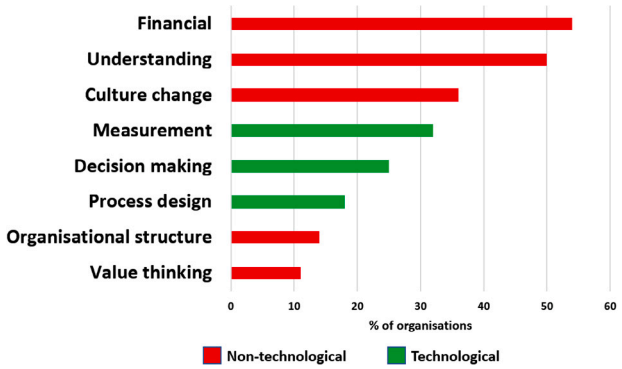

Fig. 6. Internal difficulties encountered by organisations.

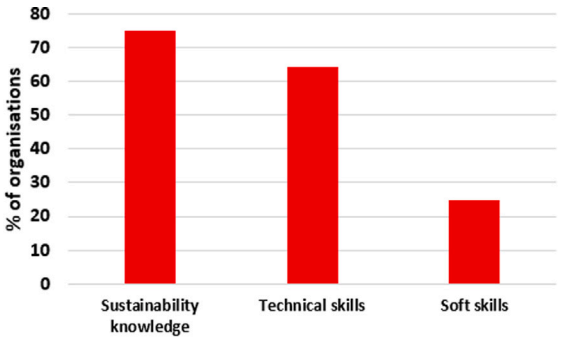

Fig. 7. Skills and competencies missing in organisations' IT workforce.

require a change of regulations to support sustainability-aware systems. Half of our interviewed organisations complained that their IT staff or colleagues need a better understanding of sustainability. At the same time, we observe that 20% of the organisations consider current policies as insufficient for driving sustainable development, and 16% struggle to persuade customers to pay more for sustainable products. This shows that even though customers want to buy more sustainable products, they are not necessarily willing to pay more. This is where politics can play a vital role in enforcing incentives, such as reducing taxes on green products and putting in place laws and adequate regulations. While non-technological issues seem to worry organisations more, they also drew our attention to the need for sustainability-related improved metrics, design processes and tools.

(On RQ3) More sustainability skills and competencies are needed due to their rising importance. Future educational programmes must be built upon three pillars: technology, soft skills, and sustainability knowledge.

As educators, we believe that IT and sustainability are disruptive forces in today's society and will increasingly converge (Oppenheim et al., 2017). Education programmes that give IT professionals strong soft- and sustainability skills will ease this process, both because it will set a basic common ground for collaboration among experts in both fields and because it will encourage every technical system to be built with essential sustainability characteristics in place.

Many organisations have recognised the need for sustainability skills and competencies for their IT staff. As shown in Fig. 7, the majority of our interviewed organisations agree that their IT workforce lacked sustainability knowledge and understanding (75%), and technical skills to implement sustainability (65%). Also, one-quarter of the interviewees pointed to the need for additional soft skills.

Based on our observations, weaknesses regarding sustainability skills and competencies of the current IT workforce can lead to (1) difficulty in understanding sustainability in the business context, including sustainability strategies, approaches, and tools to support sustainable business models, (2) difficulty in translating business requirements into IT products and services with sustainability considerations, and (3) poor communication and soft skills, which is a classic problem with software engineers and programmers.

6. Comparison to related work

Our study differs from Groher and Weinreich (2017) in several aspects. First, we interviewed 28 organisations spread across 9 countries, instead of a single country, which potentially provides a broader and less culturally biased view of sustainability in the ICT industry. Most importantly, our interviewees had different profiles. While Groher and Weinrich interviewed technical leaders of ICT projects, we talked to senior management and sustainability experts within the company. That can be observed in the different perceptions of sustainability. In Groher and Weinrich's work, most interviewees related sustainability to maintainability, extensibility, product development, and long-lived systems (Groher and Weinreich, 2017), while in our study, sustainability was more broadly understood, with the different dimensions mentioned. A remarkable difference is that the environment was very rarely mentioned in the previous study, while it was one of the main concerns shown in ours. However, both studies coincide in that the economic benefit is the greatest motivation for these companies. Both studies also looked into difficulties or deficiencies in sustainability. In Groher and Weinrich's, participants mainly pointed to a "lack of effective means for communication and knowledge sharing" and suggested strategies such as "knowledge distribution, avoiding specialists, and building teams that can work across products". Our study coincided with the lack of understanding of sustainability concepts and goals, yet it highlighted the trade-off between short-term financial profitability and long-term sustainability goals as a major difficulty. Our study also pointed to external difficulties, such as economic barriers and inadequate policies, which were not mentioned in the previous study.

Our study differs from (de Souza et al., 2014)'s significantly. They interviewed software developers within a single academic organisation. That meant that their participants were mostly experienced with research projects, which are of a very different nature from those of our study. Unsurprisingly, participants' views in that study were very much more related to technical sustainability than ours. Interestingly, their questions were open and neutral, not really biasing the answers to such limited views. Finally, the coverage of the research questions as well as the depth of the interviews was very different, with ours specifically asking about goals, barriers and skills to sustainability and theirs on the relation of sustainability with software systems. This difference in depth can also be seen in the lengths of the interviews, which typically lasted around 10 min in the previous study and 1–2 h in ours.

In contrast to the Brazilian study (Karita et al., 2021), our study aims further and, more concretely, at companies with such awareness to retrieve their actual interests, difficulties and achievements, and skills they have in-house and those that they miss.

The work in Chitchyan et al. (2016) is also based on interviews in several countries. In contrast to our study, however, the work focuses on what hampers the adoption of sustainable design principles based on Becker et al. (2015b) daily work practices, and not on the broader questions of industry sustainability-related interests and needs, their planned achievements, and the thus-required skills.

The lack of means and responsibilities perceived by the software engineers interviewed in Betz et al. (2022) differs greatly from our interviewees, who do recognise the need for sustainability skills and competencies for IT staff.

Similar to the much narrower and domain-specific (Kasurinen et al., 2017), we nevertheless also found a lack of a broader understanding of sustainability among IT professionals — and thus a clear need for action.

7. Threats to validity

We discuss our reasoning concerning the validity and limitations of this study by following the scheme described in Runeson and Höst (2009).

Construct validity. This aspect is related to whether during the interviews we asked the right questions according to our investigation objectives. To mitigate this threat, we formulated the questions by leveraging the background knowledge of the involved researchers, who have experience in these types of research in software engineering in general, for at least ten years, and in software engineering related to sustainability for at least five years. We implemented researcher triangulation through the execution of independent coding, followed by a collaborative merging of codes and subsequent discussion.

Based on our prior experiences, we acknowledge the challenge of engaging companies in focus group interviews without establishing trust. We have maintained professional relationships with several companies from prior research, though not exclusively in the realm of sustainability. The selected interviewed subjects hold pivotal positions within their respective organisations. They were chosen to provide insights into the current status and imperative sustainability requirements within their corporate entities, primarily focusing on factual knowledge rather than personal opinions regarding the subject matter. Confidentiality was emphasised to encourage them to respond to the interview questions in the most truthful way. We deliberately excluded individuals affiliating with environmental activism to maintain objectivity in our research.

Internal validity. This is related to how we executed the study internally and analysed the results to avoid unknown factors that may influence the study's outcome. To mitigate this threat, we have taken the following actions. First, to improve the instrument (i.e., interview guide) used in the study, we spent time discussing the interview questions to ensure they covered our stated research questions and avoid leading questions. During the data analysis, we adopted the following procedures consisting of two steps. In the beginning, the researchers who were the interviewers of one interview session paired with another researcher, and both performed data coding for the whole transcript obtained. After that, all the researchers involved in this study were divided into three groups, with each being responsible for each research question stated in 3.1 and having at least three members. All group members responsible for one research question validated the coded data related to their section in all the transcripts. At this stage, some recodings happened in collaboration with original coders to extract more details from the data.

External validity. This is concerned with the limitations of how much this study can generalise conclusions. There are a few limitations associated with this study. First, although we achieved quite a spread of geography (mainly in Europe), company sizes, and business domains, they are not representative of the entire European IT economy. Had we interviewed other organisations, it is possible that the results would have differed to some extent. Although we asked the companies about their interest in sustainability, it is hard to find a common pattern and reasons for the variation of sustainability among organisations, we cannot establish a connection between particular types of companies to what kind of interest in sustainability they have.

Second, our results can not only be subject to the inherent limitations of the codebook and the coding process but also to the biases of those interviewed and to the ontological uncertainty of the future. In particular, the frequency a code has been mentioned, while possibly representative of the perceived relative relevance within the industry nowadays, may not represent the true importance of each topic, which might only become apparent in the future.

Reliability. This aspect concerns to what extent the data and the analysis depend on specific researchers. Since the researchers of this study were responsible for conducting 1–3 interviews/focus group interviews, we prepared a presentation containing all the interview questions and showed it during the meetings with our interviewees to ensure all the discussions flowed consistently. In addition, we supply the codebook as supplementary materials for validation purposes, which are helpful for replication.

8. Conclusions and future work

Our study has uncovered how sustainability is viewed and practiced in 28 organisations from nine countries. The findings of this work include (i) how sustainability is of interest to these organisations, (ii) sustainability goals they want to achieve, (iii) difficulties they have encountered so far, (iv) skills and competencies needed to achieve the established goals, and (v) current practices to fill the perceived sustainability skill gap. Identifying those current practices, especially the gaps, gives us an indication of possible improvements to current university education programs with respect to sustainability for IT and related fields. This study represents the first step to improving the computing curricula to better meet the demands of industry. The results form a good basis for identifying essential topics relevant to sustainability in IT that should be taken into account when developing the curricula. Among others, it is clear from our study that relevant topics are knowledge and skills on core sustainability concepts, system thinking, soft skills, building the business case for sustainability, sustainability impact and measurements, values and ethics, standards and legal aspects, and advocacy and lobbying.

The organisations we interviewed provide only a partial geographical perspective; our analysis should be performed globally. We thus plan to survey on a global scale to obtain a more comprehensive picture and to be able to conduct quantitative analyses, for example, regarding the variation of sustainability among organisations. As it is easier to include more companies in a survey than in an interview series, this will also allow the mapping of individual business domains and different sustainability perspectives. Finally, the ultimate future goal is the development of software engineering and computer science curricula which include sustainability concepts at their very core. These curricula should certainly be holistic and not aim exclusively at the skills needed by industry. However, given the growing sustainability interest of the industry and its immense transformational power, the curricula should definitely take its sustainability needs into consideration.

CRediT authorship contribution statement

Rogardt Heldal: Conceptualisation, Data collection, Data analysis, Paper writing, Paper review. **Ngoc-Thanh Nguyen:** Conceptualisation, Data collection, Data analysis, Paper writing, Paper review. **Ana Moreira:** Conceptualisation, Data collection, Data analysis, Paper writing, Paper review. **Patricia Lago:** Conceptualisation, Data collection, Data analysis, Paper writing, Paper review. **Leticia Duboc:** Conceptualisation, Data collection, Data analysis, Paper writing, Paper review. **Stefanie Betz:** Conceptualisation, Data collection, Data analysis, Paper writing, Paper review. **Vlad C. Coroamă:** Conceptualisation, Data collection, Data analysis, Paper writing, Paper review. **Birgit Penzenstadler:** Conceptualisation, Data collection, Data analysis, Paper writing, Paper review. **Jari Porras:** Conceptualisation, Data collection, Data analysis, Paper writing, Paper review. **Rafael Capilla:** Conceptualisation, Data collection, Data analysis, Paper writing, Paper review. **Ian Brooks:** Conceptualisation, Data collection, Data analysis, Paper writing, Paper review. **Shola Oyedeji:** Conceptualisation, Data collection, Data analysis, Paper writing, Paper review. **Colin C. Venters:** Conceptualisation, Data collection, Data analysis, Paper writing, Paper review.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The supplementary can be accessed at the following links: Interview guide: https://bit.ly/390MQju Codebook: https://bit.ly/3wgt0dp.

Acknowledgements

The authors would like to thank all the interviewees who took part in the study and the reviewers for their valuable feedback. This work is supported by SFI SmartOcean NFR, Norway Project 309612/F40, by KISS, United States (16DHBKI061) with the financial support of the Federal Ministry of Education and Research, Germany, by NOVA LINCS, Portugal (UIDB/04516/2020) with the financial support of FCT.IP, Portugal, Portugal, by the Catalan Government (Departament de Recerca i Universitats) for the grant 2021 SGR 01396 given to the HER group, and by the funding from the VU Digital Sustainability Center (DiSC), the Netherlands.

References

Becker, C., Betz, S., Chitchyan, R., Duboc, L., Easterbrook, S.M., Penzenstadler, B., Seyff, N., Venters, C.C., 2015a. Requirements: The key to sustainability. IEEE Softw. 33 (1), 56–65.

Becker, C., Chitchyan, R., Duboc, L., Easterbrook, S., Penzenstadler, B., Seyff, N., Venters, C.C., 2015b. Sustainability design and software: The karlskrona manifesto. In: 2015 IEEE/ACM 37th IEEE International Conference on Software Engineering. Vol. 2, IEEE, pp. 467–476.

Betz, S., Lammert, D., Porras, J., 2022. Software engineers in transition: Self-role attribution and awareness for sustainability. In: Proceedings of the 55th Hawaii International Conference on System Sciences.

Bocken, N.M., Geradts, T.H., 2020. Barriers and drivers to sustainable business model innovation: Organization design and dynamic capabilities. Long Range Plan. 53 (4), 101950.

Brundtland, G.H., Our Common Future: Report of the World Commission on Environment and Development. Technical Report A/42/427, United Nations.

Chitchyan, R., Becker, C., Betz, S., Duboc, L., Penzenstadler, B., Seyff, N., Venters, C.C., 2016. Sustainability design in requirements engineering: State of practice.

Cohen, L., Manion, L., Morrison, K., 2017. Research Methods in Education, eighth ed. Routledge, London, England.

Cooper, V., Molla, A., 2017. Information systems absorptive capacity for environmentally driven IS-enabled transformation. Inf. Syst. J. 27 (4), 379–425.

Coroama, V.C., Hilty, L.M., 2009. Energy consumed vs. Energy saved by ICT-a closer look. In: EnviroInfo (2). pp. 347–355.

Coroama, V., Mattern, F., 2019. Digital rebound – why digitalization will not redeem us our environmental sins. In: Proceedings of the 6th International Conference on ICT for Sustainability. ICT4S 2019, Lappeenranta, Finland.

de Souza, M.R., Haines, R., Jay, C., 2014. Defining sustainability through developers' eyes: Recommendations from an interview study. In: 2nd Workshop on Sustainable Software for Science: Practice and Experiences. WSSSPE2.

Dzhengiz, T., Niesten, E., 2020. Competences for environmental sustainability: A systematic review on the impact of absorptive capacity and capabilities. J. Bus. Ethics 162 (4), 881–906.

Easterbrook, S., Singer, J., Storey, M.-A., Damian, D., 2008. Selecting empirical methods for software engineering research. In: Guide to Advanced Empirical Software Engineering. Springer, pp. 285–311.

Escoto, X., Gebrehewot, D., Morris, K., 2022. Refocusing the barriers to sustainability for small and medium-sized manufacturers. J. Clean. Prod. 130589.

Eurostat, 2016. NACE rev 2-statistical classification of economic activities in the European community. Luxembourg.–2008.

Groher, I., Weinreich, R., 2017. An interview study on sustainability concerns in software development projects. In: 2017 43rd Euromicro Conference on Software Engineering and Advanced Applications. SEAA, IEEE, pp. 350–358.

Hilty, L.M., Aebischer, B., 2015. ICT for sustainability: An emerging research field. In: ICT Innovations for Sustainability. Springer, pp. 3–36.

Judith, H., 2022. The importance of skills for the sustainability of business. URL https://bpf.co.uk/sustainable_manufacturing/introduction_to_sustainability/Importance_of_skills.aspx.

Karita, L., Mourão, B.C., Martins, L.A., Soares, L.R., Machado, I., 2021. Software industry awareness on sustainable software engineering: a Brazilian perspective. J. Softw. Eng. Res. Dev. 9, 1–15.

Kasurinen, J., Palacin-Silva, M., Vanhala, E., 2017. What concerns game developers? A study on game development processes, sustainability and metrics. In: 2017 IEEE/ACM 8th Workshop on Emerging Trends in Software Metrics. WETSoM, IEEE, pp. 15–21.

Kontio, J., Bragge, J., Lehtola, L., 2008. The focus group method as an empirical tool in software engineering. In: Guide to Advanced Empirical Software Engineering. Springer, pp. 93–116. http://dx.doi.org/10.1007/978-1-84800-044-5.

Lago, P., Kazman, R., Meyer, N., Morisio, M., Müller, H.A., Paulisch, F., 2013. Exploring initial challenges for green software engineering: summary of the first GREENS workshop, at ICSE 2012. ACM SIGSOFT Softw. Eng. Not. 38 (1), 31–33.

Lago, P., Koçak, S.A., Crnkovic, I., Penzenstadler, B., 2015. Framing sustainability as a property of software quality. Commun. ACM 58 (10), 70–78.

Malmodin, J., Bergmark, P., Lövehagen, N., Ercan, M., Bondesson, A., 2014. Considerations for macro-level studies of ICT's enablement potential. In: 2nd International Conference on ICT for Sustainability. ICT4S 2014, pp. 179–188.

Mann, S., 2011. The Green Graduate: Educating Every Student as a Sustainable Practitioner. ERIC.

Morgenstern, E.K., 2007. The origin and early application of the principle of sustainable forest management. Forestry Chronicle 83 (4), 485–489.

OECD, 2017. Entrepreneurship at a Glance 2017. p. 148, URL https://www.oecd-ilibrary.org/content/publication/entrepreneur_aag-2017-en.

Oppenheim, J., Boyd, O., Campbell, G., Dewan, N., Evans, A., George, M., George, S., Klintworth, G., Kortenhorst, A., McLeod, D., Potocnik, J., Sawers, C., Shah, A., 2017. Better business, better world. Bus. Sustain. Dev. Comm..

Rogers, M., Pfaff, T., Hamilton, J., Erkan, A., 2015. Using sustainability themes and multidisciplinary approaches to enhance STEM education. Int. J. Sustain. Higher Educ..

Runeson, P., Höst, M., 2009. Guidelines for conducting and reporting case study research in software engineering. Empir. Softw. Eng. 14 (2), 131–164.

Seele, P., Lock, I., 2017. The game-changing potential of digitalization for sustainability: possibilities, perils, and pathways. Sustain. Sci. 12 (2), 183–185.

Stone, J.A., 2019. A sustainability theme for introductory programming courses. Int. J. Modern Educ. Comput. Sci. 11 (2), 1.

Terrafinity, 2023. Sustainability skills for everyone...not just the professionals. URL https://www.terrafiniti.com/sustainability-skills-for-everyone-not-just-the-professionals/.

Vaismoradi, M., Jones, J., Turunen, H., Snelgrove, S., 2016. Theme development in qualitative content analysis and thematic analysis. J. Nurs. Educ. Pract. 6 (5), 100–110.

Vehovar, V., Toepoel, V., Steinmetz, S., 2016. Non-probability sampling. In: The Sage Handbook of Survey Methods. Sage Thousand Oaks, pp. 329–345.

Venters, C.C., Capilla, R., Betz, S., Penzenstadler, B., Crick, T., Crouch, S., Nakagawa, E.Y., Becker, C., Carrillo, C., 2018. Software sustainability: Research and practice from a software architecture viewpoint. J. Syst. Softw. 138, 174–188.

Von Carlowitz, H.-C., 1732. Sylvicultura Oeconomica Oder Haußwirthliche Nachricht Und Naturmäßige Anweisung Zur Wilden Baum-Zucht, vol. 1, Bey Johann Friedrich Brauns sel. Erben.

Watson, M.K., Lozano, R., Noyes, C., Rodgers, M., 2013. Assessing curricula contribution to sustainability more holistically: Experiences from the integration of curricula assessment and students' perceptions at the Georgia Institute of Technology. J. Clean. Prod. 61, 106–116.