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Olga Levina, Technische Hochschule Brandenburg, Germany
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ICDS 2024

Forward

The Eighteenth International Conference on Digital Society (ICDS 2024) was held between May 26th and May 30th, 2024, in Barcelona, Spain. Nowadays, most of the economic activities and business models are driven by the unprecedented evolution of theories and technologies. The impregnation of these achievements into our society is present everywhere, and it is only question of user education and business models optimization towards a digital society.

Progress in cognitive science, knowledge acquisition, representation, and processing helped to deal with imprecise, uncertain, or incomplete information. Management of geographical and temporal information becomes a challenge, in terms of volume, speed, semantic, decision, and delivery. Information technologies allow optimization in searching an interpreting data, yet special constraints imposed by the digital society require on-demand, ethics, and legal aspects, as well as user privacy and safety.

The event was very competitive in its selection process and very well perceived by the international scientific and industrial communities. As such, it is attracting excellent contributions and active participation from all over the world. We were very pleased to receive a large amount of top-quality contributions. The accepted papers covered a large spectrum of topics related to advanced networking, applications, social networking, security and protection, and systems technologies in a digital society. We believe that the ICDS 2024 contributions offered a panel of solutions to key problems in all areas of digital needs of today's society.

We take here the opportunity to warmly thank all the members of the ICDS 2024 technical program committee, as well as all the reviewers. The creation of such a high-quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and effort to contribute to ICDS 2024. We truly believe that, thanks to all these efforts, the final conference program consisted of top-quality contributions. We also thank the members of the ICDS 2024 organizing committee for their help in handling the logistics of this event.

We hope that ICDS 2024 was a successful international forum for the exchange of ideas and results between academia and industry and for the promotion of progress in the area of digital society.

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Table of Contents

Exploring the Digital Divide in Workplace Learning: A Rapid Review

Katharina Frosch
Brandenburg University of Applied Sciences
Brandenburg an der Havel, Germany
email: frosch@th-brandenburg.de

Friederike Lindauer
Brandenburg University of Applied Sciences
Brandenburg an der Havel, Germany
email: lindauer@th-brandenburg.de

Niek Zuidhof
Saxion University of Applied Sciences
Enschede, The Netherlands
email: e.n.zuidhof@saxion.nl

***Abstract*— This article examines the digital divide in workplace learning, with an emphasis on the disparity in the distribution of Advanced Learning Technologies (ALT) across different types of workplaces. The study employs a rapid literature review methodology to analyze the utilization of ALT in workplace learning. The findings indicate that the use of ALT is predominantly concentrated in the education, health and medical sectors, with limited implementation in other sectors. Moreover, in smaller organizations, in non-technical sectors and among white-collar workers, there are fewer opportunities for technology-enhanced learning. The study highlights the need for more inclusive and comprehensive research to address the digital divide in workplace learning, taking into consideration practice-based evidence and exploring the themes covered by training. Furthermore, the paper proposes an investigation into the complexity and resource intensity of implementing ALT to enhance technology-based learning in all workplaces. In general, this research establishes the basis for comprehending and bridging the digital learning divide in the workplace.**

Keywords-advanced learning technologies; technology-enhanced learning; digital divide; workplace learning.

I. INTRODUCTION

A large share of lifelong learning occurs during and alongside work and often has a rather informal character [1] [2]. In this context, much is foreseen from Advanced Learning Technologies (ALT). ALT are characterized by careful instructional design, a high degree of interactivity and a holistic approach to the assessment of learning outcomes [3]. Some examples for ALT are adaptive learning systems, mobile micro-learning, augmented or virtual reality applications and even digitally supported types of collaborative ("social") learning. When designed well, these technologies can make self-regulated learning-on-the-go at the workplace easier, allowing individuals to take control of their learning and regulate it according to their needs [4]-[6].

A particular concern, however, is that access to technology-enhanced learning opportunities is not the same for all workers, which systematically deprives those employed at workplaces with little ALT-enhanced learning opportunities from nurturing their employability and fostering their individual professional development and growth. The scope of our research is to gain insights in the relative distribution of opportunities to benefit from ALT for re- and upskilling in the workplace, i.e., the digital divide in workplace learning.

A deeper understanding of the digital divide in workplace learning could be a step towards more equitable access to ALT, which facilitates personal and professional growth, employability, and thus the advancement of social justice and inclusion. In conclusion, addressing this divide not only enhances organizational competitiveness but also provides new perspectives for comprehensive and inclusive workforce development policies.

The paper is structured as follows. Section II describes the State-of-the-Art. Section III presents the methodological design of the literature review, followed by the description and interpretation of results in Section IV. Section V concludes with some future directions of research.

II. STATE-OF-THE-ART

In the past, inequalities in access and use of Information Technology (IT) have been discussed against the backdrop of the concept of the "digital divide", i.e., "digital inequalities between individuals, households, businesses or geographic areas" that arise from disparities in physical access to IT infrastructures, digital competency of users but also in unequal capabilities, engagement, and use outcomes [7]. So far, the digital divide has been, for example, discussed at the individual (i.e., age, income, educational level, digital competencies, language barriers) level and the regional level (country, remote areas vs. rural areas) [8]. During the COVID-19 pandemic, we have experienced firsthand that the digital divide can severely limit access to education for those who are digitally left behind [9]-[12], leading to reduced education equity [13]. To our knowledge however, there is no systematic analysis yet that sheds light on the digital divide in *workplace* learning, i.e., processes related to learning and training activities at various levels of an organization, thus *at* work [14][15].

For this paper, and drawing on the general definition of the digital divide provided by [7], we define the digital divide in workplace learning by the variations in the utilization and adoption of adult learning practices across different types of workplaces. More concretely, we hypothesize that whether one works in a small or a large company, whether one works in the public or the private sector, and what job field (e.g., blue vs. white collar) one is working in severely affects one's opportunities for technology-enhanced learning. From a workplace ethics and sustainable development perspective, access to opportunities for re- and upskilling From the perspective of workplace ethics and sustainable development, access to lifelong learning opportunities should not depend on job characteristics, but should be inclusive and equitable, as required by the United Nations Sustainable Development Goals [16]. Furthermore, barriers in the access to ALT at the workplace create disparities for individual workers and puts the up- and reskilling of our workforce at risk, which is urgently needed for future employability.

Earlier studies show that the use of ALT is heavily skewed towards the educational sector [17][18], as well as towards academic professions, in particular health and medical care (ibid.) and information technology [19][20]. To give an example, in the review study by Granić [17], about 80 percent of the studies covered came from the educational field. Similarly, in the review by Yu et al. on information technology in workplace learning [20], 18 out of the 60 studies analyzed were from the medical field. There is also some evidence that ALT is less used in public services (3 out of 60 studies in the review of Yu et al. [20]) than in business enterprises [20][21] – 3 as compared to 34 in the review by Yu et al. [20] – and that smaller and medium-sized enterprises lag behind in the adoption of ALT [22].

However, even if the studies mentioned above provide informative starting points, we argue that a reliable and more granular picture of the digital divide in workplace learning is missing: Most studies rely primarily on evidence predating 2020, before the digitization boost caused by the COVID-19 pandemic. Therefore, they can be considered somewhat outdated. Two of the three studies covering very recent evidence do not [18] or not fully [22] qualify as *systematic* reviews. Recent systematic reviews cover rather specific topics such as instructional planning in e-learning [23] or the effect of technology-enhanced learning and training on organizational-level learning outcomes [19], or they focus on specific occupations and sectors, in particular those such health professionals [24] or teachers [25] where the use of ALT is frequent. The most recent systematic review by Yu et al. [20] found that only 19 out of the 60 studies analyzed (ibid, p. 4912) focused on individual employee learning processes within enterprises. The remaining studies investigate the interplay of meta-constructs, such as technology acceptance of ALT in general or satisfaction with online forms of learning at the workplace rather than focusing on individual-level workplace learning processes. However, the review does not provide a detailed analysis of institutional characteristics or delve deeply into ALT.s The current literature highlights how little we know about the varied utilization of ALT across industries, occupations, and diverse institutional settings (e.g., large vs. small, public vs. private).

To address the described gap in the literature, we propose an alternative approach to analyzing the literature on technology-enhanced workplace learning. We advocate for a shift towards examining *specific examples* of technology-enhanced workplace learning *implementations* aimed at *individual* learning processes within *distinct workplace contexts* to obtain a more nuanced understanding of the disparities in technology-enhanced workplace learning depending on the type of workplace. This approach allows us to shed light on the research question how access to digital learning opportunities is affected by the type of institution and the professional field.

III. RESEARCH DESIGN

We conducted a rapid review [26] to evaluate the digital divide in workplace learning. Rapid reviews, which fall within the framework of Cochrane review methods [27, p. 5], are a streamlined approach to gathering evidence through synthesis and have a shorter turnaround time compared to traditional systematic reviews. The following section explains the search and selection strategy that we derived from the objectives of this study – to describe the digital divide in workplace learning. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses [28][29] (PRISMA) approach was adopted to guide the screening process (see also Figure 1).

The search strategy was as follows: We identified peer-reviewed journal publications published in the English language, and focused on technology-enhanced learning at the workplace. We used the Web of Science (WoS) online database to search for relevant publications, as this database matched best our search strategy and promised an efficient identification of relevant publications (contains peer-reviewed journal publications). Only publications published in 2020 or later were included. This is because we assume that the implementation of ALT in the workplace has undergone structural changes as a result of the COVID-19 pandemic. Review articles were excluded, as we are interested in institutional-level implementations of technology-enhanced learning.

TABLE 1: CONSTRUCTION OF THE SEARCH STRING

Explanation	**Components of the WoS seach string**		
online learning or synonymous term in title referring to the use of ALT	(((TI= ("digital" OR "virtual" OR "online" OR "hybrid" OR "remote" OR "blended" OR "distance" OR "web-based") AND TI=("learning*" OR "training*" OR "course*")) OR TI=("e-learning" OR "elearning" OR "e-training" OR "entraining" OR "microlearning" OR "micro-learning" OR "mobile learning" OR "mobile-learning" OR "learning app"))		
	AND		
concrete implementations…	(AB=("case stud*" OR "company case*" OR "field stud*" OR "field experiment*" OR "questionnaire*" OR "survey*") OR TI=("case stud*" OR "company case*" OR "field stud*" OR "field experiment*" OR "questionnaire*" OR "survey*"))		
	AND		
… at the workplace	(AB=("workplace*" OR "business*" OR "industry" OR "industries" OR "enterprise*" OR "compan*" OR "public service*" OR "public sector*" OR "civil serv*" OR "corporat*" OR "professional*" OR "SME*" OR "governm*" OR "continuing education") OR TI=("employee*" OR "worker*"))		
exclude ALT applications aimed at students or pupils as well as machine learning applications	**NOT**		
	AB=("student" OR "students" OR "pupil*"OR "machine learning" OR "deep learning" OR "reinforcement learning")		
	NOT		
	TI=("student" OR "students" OR "pupil*"OR "machine learning" OR "deep learning" OR "reinforcement learning")		
	AND	AND	NOT
relate to one of the three fields	education	health and medical field	other fields
	AND	**AND**	**NOT**
	(TI=(teacher* OR faculty* OR lecturer*) OR AB=(teacher* OR faculty* OR lecturer*))	(AB=("health*" OR "care" OR "medic*" OR "surg*" OR "radiol*" OR "dementia*" OR "clinic*" OR "nurse*") OR TI=("health*" OR "care" OR "medic*" OR "surg*" OR "radiol*" OR "dementia*" OR "clinic*" OR "nurse*"))	TI=(teacher* OR faculty* OR lecturer*) NOT AB=(teacher* OR faculty* OR lecturer*)) NOT AB=("health*" OR "care" OR "medic*" OR "surg*" OR "radiol*" OR "dementia*" OR "clinic*" OR "nurse*") NOT TI=("health*" OR "care" OR "medic*" OR "surg*" OR "radiol*" OR "dementia*" OR "clinic*" OR "nurse*")

Our search string (see also Table 1) refers to different synonyms of e-learning, and made reference to real-life ALT applications in a workplace setting. The search terms underwent further refinement and revised by an information specialist at the Brandenburg University of Applied Sciences. The final search string included restrictions (e.g., students at higher education institutions, pupils at schools, machine-learning applications) for settings that do not classify as workplace learning.

Searches were conducted from February 16, 2024, to February 26, 2024, and yielded a total of 561 records (no duplicates). To account for the skewed distribution of publications on ALT towards the educational and health sectors, we conducted three separate searches for technology-enhanced learning (ibid.). These searches were conducted for educational institutions (N=130; 23% of records), for the ealth and medical sector (N=238; 42%) and for all other fields (N=193; 35%).

We recognize that this first step is merely an approximation, as we had not yet screened out records based on titles, keywords, and abstracts that may not be related to the use of ALT at the workplace. However, considering the high frequency of articles related to education and health and medical fields, and recognizing that most institutions in these fields are likely to be large and public sector-based, we believe that this approximation falls within the efficiency required by the chosen methodology (rapid reviews) while still retaining substantial validity for assessing the digital divide in workplace learning.

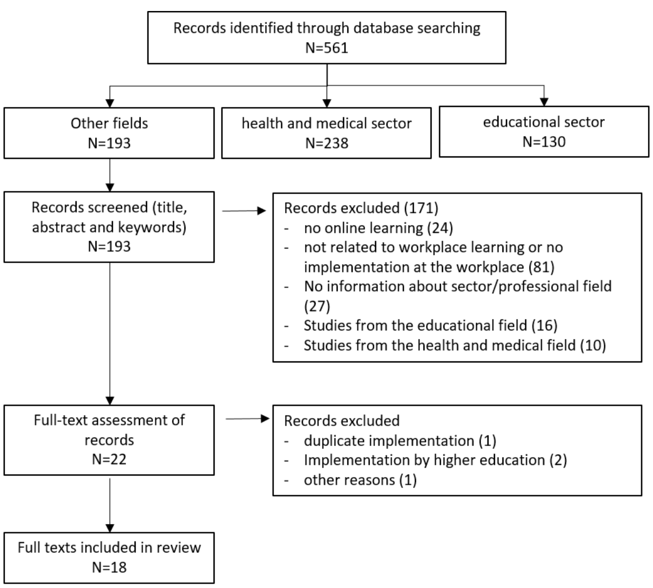

Figure 1. PRISMA chart

TABLE 2: DISTRIBUTION OF ALT-USE AT THE WORKPLACE

Study	Institution	Sector	Profession	ALT	COLL
[30]	N/A	retail	diverse	MicroL	no
[31]	large	public	diverse	MobileL	yes
[32]	several	engineering	engineers	other	yes
[33]	large	business services	white-collar	other	yes
[34]	large	automotive	blue-collar	VR	no
[35]	large	public	white-collar	MicroL	no
[36]	several	IT	IT specialists	MicroL	no
[37]	large	public	both	other	no
[38]	medium	industrial services	blue-collar	VR	yes
[39]	N/A	food	N/A	other	no
[13]	large	energy	blue-collar	VR	no
[40]	N/A	energy	blue-collar	VR	no
[41]	large	steel	blue-collar	VR	no
[42]	several	electronics	blue-collar	VR	no
[43]	several	education	other	other	no
[44]	several	public	blue-collar	VR	yes
[45]	several	agriculture	blue-collar	MobileL	yes
[46]	large	chemical	diverse	other	N/A

Notes: ALT = advanced learning technologies, COL = collaborative learning, MicoL = micro-learning, MobileL = mobile learning, VR = Immersive virtual reality training

The screening strategy for the 193 records resulting from the search for other sectors was as follows: Titles, keywords, and abstracts were screened for each record. Records that did not mention 'online' in connection with 'learning' (N=24), were not related to workplace learning or did not contain detailed information about a specific implementation at the workplace (N=81), excluding, e.g., studies focusing on organizational learning processes rather than individual learners' competency building, and studies that discuss abstract concepts or the interplay of general constructs in technology-enhanced workplace learning. Furthermore, we excluded studies without information about sector or professional field (N=27). This meant, e.g., that we exclude cross-sectional studies covering a large number of different institutions.

Furthermore, we identified additional review studies that have not been excluded in the initial WoS search routine (N=3). Similarly, we excluded further studies that refer to education (N=16) or to the health and medical field (N=10) that still ended up in the search results for "other sectors".

The remaining N=22 publications were included in full text screening. We excluded two additional studies because they were implemented and/or tested in a higher education context. Another was focused on knowledge management with MS Office and social media tools rather than with technology-enhanced learning. Moreover, we found two studies using the same ALT implementation example that we treated as duplicates and excluded one of them.

The 18 final full-text records underwent detailed analysis to gain systematic evidence on the digital divide in workplace learning. The screening was conducted with respect to the characteristics of the institution and the workplace, such as size, sector, and type of job.

IV. RESULTS

Initially, the scarcity of studies on advanced learning technologies for workplace learning beyond higher education and healthcare is noteworthy. This scarcity suggests that – at least evidence-based and scientifically evaluated – implementation of ALT in the workplace is not yet that widespread, as we would expect given the generally acknowledged importance of reaping the benefits of ALT for workplace learning. Full-text screening of the 17 relevant studies identified yields the following picture (see also Table 2): The great majority of examples of ALT use at the workplace refers to large organizations or to cross-institutional implementations with participants from several institutions (e.g., engineers or agricultural workers employed in different companies or being self-employed). Our sample only contains one example at a medium-sized enterprise, and none at a small organization. Moreover, most applications are from technical sectors, such as energy, engineering, or automotive rather than from the service sector. Immersive virtual reality training (single or multi-player) is the most frequently found ALT, followed by mobile and micro-learning implementations. The picture becomes even clearer when we look at the occupational fields targeted by ALT in the records studied: it is mainly blue-collar workers who have access to ALT, especially VR-based immersive training.

A third of the records analyzed cover ALT that fosters networked learning, i.e., collaboration between learners. Here, we cannot find differences in the use of ALT between white-collar and blue-collar professions.

V. Discussion And Conclusion

The present study examines the digital divide in workplace learning, which refers to the varying degree of use of ALT in different workplaces. By conducting a rapid literature review, we confirm existing evidence suggesting that the use of ALT is heavily skewed towards occupations in the education, health and medical sectors. It is not surprising that there is a skewness or disparity in these fields, as the institutions are typically large and resourceful organizations with a certain proximity to research-oriented practices, which may be more willing to embrace innovation and technological advances, as well as learning and training.

Further screening of the literature has revealed that there is a lack of ALT implementation at the workplace in other sectors, at least in terms of implementations that have been scientifically evaluated and the results have been published in peer-reviewed journal articles. Our results show that technology-enhanced learning opportunities are less frequent in smaller organizations, non-technical sectors (including the public sector) and for white-collar workers.

A major limitation of our research is publication bias. We may assume that the likelihood of writing an academic publication and publishing it in a peer-reviewed journal is higher in academic fields, such as health and education, which may partly explain the great number of results on the use of ALT for workplace learning we found.

Still despite these methodological limitations, our results indicate that there seems to be a digital divide in workplace learning, in particular along employer size and technological sector. Given that for example in Europe, almost two thirds of the employed workforce is working in small or medium-sized enterprises [47], and similarly, almost three quarters are employed in the service sector [48, p. 48], this poses a threat to workforce up- and reskilling and may severely hamper learning opportunities and individual development and growth for employees at such workplaces.

Further research focusing on the digital divide in workplace learning may broaden the perspective and take into account more practitioner-based evidence on ALT use at the workplace. This could be achieved by including a more inclusive database, such as Google Scholar, which also indexes conference proceedings, preprints or institutional repositories, in its search routine.

In addition to this methodological extension, it would also be interesting to determine the themes covered by the training, in order to get an even more detailed picture of the digital divide in workplace learning at the level of work tasks and duties, rather than just at the level of workplaces and institutions.

It is also an open question to what extent the digitalization and the shift to remote work, accelerated by the COVID19 pandemic, affects the digital divide in workplace learning: On the one hand, ALTs have increasingly been introduced to train workers remotely [49]. On the other hand, many people have lost their jobs during the pandemic, or have had their working hours reduced, or have been working from home in isolation, depriving them of workplace learning opportunities. It remains to be seen what long-term impact this will have on ALT-based learning opportunities for different groups.

Finally, we suggest more closely investigating the technologies used to implement ALT at the workplace, in particular concerning the complexity and resource intensity of implementation, as this might be a reason why smaller institutions use ALT less frequently to boost workplace learning. This could lead us to discover that digitally-enhanced learning functions as a Socio-Technical Information System (STIS) [50]. As our paper emphasizes, ALT systems may currently be sub-optimally designed, as many of them were originally developed for or by large private companies, or tailored to educational institutions, overlooking the diverse reality of institutions that lack experience in ALT provision and would rather need lightweight approaches for implementation.

In summary, our paper sets the stage for an in-depth exploration of workplace disparities in accessing ALT, laying the foundation for understanding the digital learning divide. By acknowledging the socio-technical nature of ALT and its current suboptimal design, we pave the way for future discussions on optimizing technology-enhanced learning for all workplaces, regardless of size, sector, or individual characteristics.

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The Human Side of RPA – Contextualizing Process Actors and RPA Implementation

Olga Levina
Brandenburg University of Applied Science
Brandenburg an der Havel, Germany
e-mail: levina@th-brandenburg.de

***Abstract*—Robotic Process Automation (RPA) is gaining attention in research as its implementation in the practice is growing. As a form of business process automation, it is part of the toolbox of business process analysts, managers, and IT departments. Nevertheless, the integration of process workers into RPA implementation projects has received relatively little attention despite its importance for the acceptance and use of RPA-technology. This study examines the involvement of process workers in RPA projects from a business analyst's perspective based on four qualitative interviews. The findings affirm previous research on the origins of RPA project implementation and performance indicators while outlining issues in the implementation and maintenance phases. The perception of the integrated RPA and its effects on the processes by process workers show mixed reactions, where fear of job loss and questioning the automation necessity prevail.**

Keywords: Robotic Process Automation; Business Process Management; technology implementation; participation; employee wellbeing.

I. INTRODUCTION

As companies demand an increasing degree of process automation to stay competitive in their markets, the use of Robotic Process Automation (RPA) as part of their Information Technology (IT), constitutes a 'highly promising approach' [1] that an increasing number of companies rely upon to optimize and implement their internal business processes [2]. As such, this technology has the potential to be included in the Business Process Management (BPM) standard toolbox [3]. RPA uses software based on machine learning techniques to automate repetitive rule-based manual tasks within business processes. Since its introduction in the early 2010s, it has gained popularity in business process automation [4]. RPA offers the potential to automate business processes by taking over the role of employees and streamlining routine tasks without the need for complex programming [5].

However, still many of the initial RPA projects fail. Hence, it is necessary to identify suitable processes and determine the automation requirements for each process step and use BPM approaches to optimize processes or tasks before their automation. Another aspect of successful technology implementation is its acceptance by future users [6], [7]. Thus, the goal of this study is to explore the status quo of the involvement of process actors in the implementation of RPA projects. Focusing on the workforce, this study also explores measures of RPA success in terms of process performance and the role of security, as suggested by Zhang et al. [7]. It uses qualitative interviews with four business analysts and software developers from Germany with experience in RPA implementation projects.

Based on the qualitative analysis of the interviews as described by Mayring [8], the findings are in line with the research that shows that RPA projects are driven by middle management or organizational units [7], [9], while displaying that the input from affected units and feedback from business units are also being considered. From the implementation perspective, the findings indicate that implementing and maintaining RPA is a significant undertaking that requires additional maintenance effort compared with traditional software. On the other hand, employees' reactions to RPA projects vary. Post-implementation perception shows improvements in job satisfaction but also challenges related to employee acceptance and perception in the initiation phase. Factors such as fear of change and the time required to adapt contribute to the limited enthusiasm and acceptance of the technology from the process workers. The paper analyses the question of how the opinions and needs of the process workers are considered for the integration of RPA technology in the process. The results of the analysis can be used by process owners, process managers as well as RPA project teams and engineers to ensure an effective technology integration that also considers the opportunities and challenges of the involved process actors.

The paper is structured as follows: first, in section II, the research on RPA implementation and employee involvement is reviewed. Research questions and method are presented in Section 3. The findings are summarized in Section 4. Discussion and outlook finish the paper.

II. RPA Implementation Approaches

RPA has been widely adopted in a diverse set of business functions, such as accounting, human resources, finance, supply chain management, marketing, and IT. Many processes in these functions are standardized [10]. In terms of the industrial domain where these services are used, financial services are among the sectors that are the farthest ahead in RPA adoption. Riedl and Beetz [11] provide a literature review that results in the description of the factors to determine business processes that are suitable for RPA integration. Building on this work, Wewerka and Reichelt [2] derive from their literature analysis that best suited for RPA automation are repetitive, rule-based, and complex business processes demanding high manual efforts. Furthermore, as RPA can automate different process tasks, it is designed to be easily implemented and used, and does not require modification of existing IT infrastructures [12]. The RPA literature focuses mostly on successful RPA projects and the positive effects of the RPA implementation, leaving room for further research on failed projects and the challenging effects of the implementation of the technology. The positive effects mentioned in the literature review by [2] can be summarized as resulting in faster, better available, more compliant, and business processes with improved quality. Herm et al. [13] offer a flexible framework as guidelines to be applicable in complex and heterogeneous corporate environments for RPA implementation. They identify three stages of RPA project: initialization, implementation, and scaling. Being focused on the BPM side of project management, process workers are not factored into this implementation framework.

Nielsen et al. [14] suggest five key factors for successful RPA implementation in supply chains. These factors are: prioritizing the benefits that can be obtained through the RPA initiative, performing a feasibility study, assembling a cross-functional team, having a team leader and receiving support from top management. While focusing on the business benefits and project management, the authors leave the role of process out of scope. Nevertheless, automation in the workplace and the adoption of new technologies can affect employees' work experiences in both positive and negative ways [6]. Plomp and Peeters [15] found in their extensive literature review that the implementation of new technology was associated with intensified job demands, including job complexity and workload. Job demands are, e.g., workload, time pressure, and role conflict. They refer to the facets of a job that require continuous cognitive or emotional effort and hence are related to physiological or psychological costs [16]. RPA technology is currently being designed to make administrative work procedures streamlined and effective, which is supposed free up employees' time for more creative work [17].

Nevertheless, RPA significantly alters some tasks and their design, but it does not automate and replace all aspects of jobs [18]. Implementing RPA in the existing business processes thus, might alter how employees perceive their work, leading to better or worse designed jobs and therefore probably impacting key outcomes related to employee work experiences and wellbeing [15], [18].

The negative impact of RPA on process workers has been analyzed by Peeters and Plomp [6]. Their research revealed that RPA use was negatively related to both autonomy and task variety as job resources, which formed a threat to employee work engagement. Furthermore, they pointed out that the negative association between RPA use and autonomy and task variety could lie in the ongoing implementation process of workplace automation.

Hence, this study follows the call for research by Wewerka et al. [2] and takes into the same line as Peeters and Plomp [6] by addressing process performance indicators in RPA projects but also the question about the perception of the technology by the process workers. The research questions are thus: where during the RPA implementation project is the wellbeing of the process workers being considered and what process optimization factors are expected to be advanced using the RPA.

III. Research Method

To answer the research questions mentioned above, semi-structured interviews were conducted with four RPA implementation experts from German companies that had actively participated in RPA implementation.

TABLE I. Overview of the interview partners for the study.

Interviewer ID	Position	Project domain
1	IT Consulter	Logistics, finance
2	Senior Software Engineer	Logistics, finance
3	Senior IT Consulter	Finance
4	IT Manager	Logistics

The interviews were led in June 2022 via a video conference tool, anonymized and transcribed for qualitative content analysis [11]. For the purpose of the paper, the relevant parts of the interviews were translated from German to English.

Table 1 shows the overview of the interview partners and their roles in the discussed RPA project (see Table 1). In these projects, software engineers are responsible for the development, testing and documentation of the robots, i.e., the software code. They worked closely with the companies that initiated the RPA implementation project and were responsible for maintaining and improving the robots during the project. RPA IT consultants have the process knowledge and experience with the business processes and process steps that are being automated with RPA. Since RPA technology is used across different domains, the interviewed experts could

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provide their insights based on experience from different industries.

Content analysis was following the categories of the research questions: Process initiation, process performance indicators, technology implementation and maintenance, technology operationalization, involvement of the process workers, benefits from RPA implementation for process workers, reaction to the project initiation by the process workers Besides process errors (error rate) and rework, security was coded as part of the process quality dimension during the content analysis. The respective indicators were privacy, information security, and access misuse [19]. A detailed overview of the performance indicators as well as the transcripts of the interviews as well as the survey questions can be obtained upon request (see author's email).

IV. SUMMARY OF THE RESULTS

The findings from the interviews are presented here in the categories of the research questions that were also the guiding categories of the content analysis. To understand the influence of employee requirements on the RPA projects and implementation, the initiative for the project initiation was surveyed. Since the technology can support routine and monotonous tasks, project initiation can come from the process workers. Correspondingly, given the complexity of the interaction of the legacy process and the newly introduced technology, it was expected that the roles for its further maintenance were also defined in cooperation with the process workers. Process performance indicators were surveyed in the interview to understand the impact of RPA on the process. Further questions were focused the actual involvement of the process workers and the expected as well as actual benefits and reactions of the process workers.

A. *Project initiation and continuity*

The interview partners mentioned that the initiative for the RPA projects originated from IT consultants already present in the enterprise, central organizational units that monitor innovative technology implementations, or managers who perceived potential cost savings by the introduced technology that was going to be achieved, among others, via reducing the workforce.

"*I was the initiator when it came to implementing RPA. And the second person who significantly initiated [the project] was the finance commercial manager."* (Interview partner 4, 00:04:22)

"*The initiative came from an innovation team, as they are responsible for providing impulses for innovation, for AI, blockchain, or the use of RPA in the bank. In the next step, it was discussed with the management board and the executive board*". (Interview partner 3, 00:08:14)

"*The automation idea came from the management level, but employees are against it, you can tell*." (Interview partner 2, 00:58:40)

"*Most often, the idea comes from managers who can save [costs] by chasing away employees*." (Interview partner 2, 01:05:05)

One interview partner added that the introduction of the RPA technology was motivated by its availability and costs as well as enhanced process quality and thus was meant to replace human workers:

"*The main motivation, I would also say, is actually these two points. On the one hand, you have to prevent having to hire more people for traditional clerk jobs by saying that before you hire new clerks, you first try to automate things, make things more efficient, so that you don't have to make the investment in new employees and try to automate things and, on the other hand, minimize the risk [of human error] [. . .]*". (Interview partner 3; 00:07:08)

However, it is noted that the selection of processes for automation includes input from the affected business units, with a focus on small and less complex processes first, in order to showcase the benefits of RPA. The feedback considering these implementations is collected from, e.g., line managers, but not from the process workers.

"[. . .] provide a computer on which you can run RPA, just with sample data [. . .] of course, then let the whole thing run through. The department checks whether the result [. . .] fits or doesn't fit. Then, [. . .] RPA is really implemented on a company's computer using which you can work with the original data". (Interview partner 1, 00:05:27)

Implementing and maintaining RPA is recognized by the interview partners as a significant undertaking, requiring more maintenance effort compared to the development of the traditional software. Interview partner 1 stressed that RPA implementation and maintenance is a project that should not be underestimated.

"The decisive factor for the implementation of RPA, which I think is always left out a bit, is that it also requires a great deal of maintenance and a great deal of effort to maintain the processes themselves. You can't neglect that. It is also more maintenance effort than if you now develop software and then make it available." (Interview partner 1, 00:35:01).

B. *Process Performance Indicators*

Key Performance Indicators (KPIs) play a crucial role in the reviewed RPA projects in the interviews, aiding in the identification of automation potential and evaluating the success of the implementation. The following indicators were derived from the research on process performance and were approved as measurable and useful by the interview partners: Process cycle time, processing availability, and cost savings. Process costs are assessed as decreasing after the RPA implementation, e.g., due to the bridging function of the RPA between the legacy systems and new software:

"*The API interface is not typically located between web-based platforms and core banking system in banks is often* *outdated, sometimes 20 years or older. Investments are too expensive, to build a new banking system*." (Interview partner 3, 00:16:44)

Higher quality, i.e., less mistakes during data transformation, are considered an additional benefit. Furthermore, the interview partners delivered estimation from their experience of the RPA implementation on some of the KPIs:

"*The throughput time has gone down for entire processes. I can definitely say that the throughput time has gone down. Also [the] error rate*." (Interview partner 1, 00:47:22)

However, the interviews suggest that process security aspects receive relatively low attention from the RPA implementation team. Their importance is also dependent on the domain the technology is being implemented in. Data protection regulations and industry-specific requirements can hinder the implementation of RPA projects all together, as the compliance with these regulations needs to be ensured before proceeding.

"*The security analysis depends on processes and if something changes or is delated and something goes wrong with the process, you must be able to start over* [. . .]". (Interview partner 4, 00:36:51)

"*In a banking context, you have always to assess a certain data protection class when dealing with the data in IT. Depending on the classification, it can even be impossible to implement the process, or you must first ensure that data is protected. If you deal with customer data, it must be ensured that the data is secured. That includes the data protection analysis and data classification*". (Interview partner 3, 00:19:41)

C. Involvement of the Process Workers

Concerning the question about the involvement of the process workers, the interview partners were relying on their impressions from the communication with process workers during the process analysis phase and during the technology implementation. The anonymous survey directed at collecting the information directly from the employees was designed by the researchers but did not receive any responses. Thus, the described results offer only indirect insights on this topic. The interview partners stated that the involvement of process workers in the RPA- implementation project received little attention from the project team. One tool for employee communication, the awareness session, was mentioned. It aimed to describe the project's goals, processes, and outcomes to the employees from the affected business unit.

The supplementary goals of the meeting were to assure the participation of the process workers during the process analysis and also to prepare the employee for the changes in their responsibilities and tasks after the project.

"At the bank we offered the awareness session to explain how to identify the processes".

"We have always done awareness sessions, to explain what RPA is. In the cooperation with the business unit, we started firstly with the collecting of KPIs, to understand how often the processes is executed, what is the data format, whether this manual process can be automated". (Interview partner 3, 00:29:57, 00:03:20)

D. Benefits for Process Workers

As perceived by the interview partner, employee perception in the post-implementation phase shows improvements in job satisfaction, as employees no longer have to perform tedious tasks and the overtime rate has gone down.

"What I took from the [interactions with] employees, [is] this [job] satisfaction. Because there were many of these processes that annoyed them when they had to perform [them]. I can say that RPA has made things much better in many cases. [. . .] Overtime rate is [allegedly] going down because you don't have to do that tedious work anymore. [Thus,] Advanced training rate can go up, because you have more time to do training." (Interview partner 1, 00:49:30)

"Due to the compliance requirements in the financial sector, a human actor is required to approve some of the process results that were derived using RPA. Hence, the amount of work for the human actor decreases." (Interview partner 2, 00:36:41).

One interview partner mentioned that employees that were working in the now RPA supported process can now become inhouse IT developers or business analysts:

"*That is, the time that is freed up, in the automated process, can be used to also think about making the activities more efficient. Classic role in the case [would be] business analyst, which may not have existed before." (Interview partner 4, 00:13:05).*

"Another possibility is also [. . .], if IT skills are available in the business unit [or with the process worker], development can of course also be carried out by the business unit." (Interview partner 4, 00:15:17)

E. Reaction of the Process Workers

However, employee reactions to the announcement of the RPA project vary, with some questioning the need for automation and others suggesting specific parts of processes for automation while highlighting the value of their expertise.

"*Another dark topic is acceptance. From my experience cheering is rarely seen, that is, it keeps within limits. There are many reasons for this: fear of change, costs of (personal) energy, time to adapt. Automation often brings new problems: IT must be built, licenses purchased (costs money, personnel, stress of the employees (due to new tasks formats, etc.)"*. (Interview partner 2, 01:05:05)

During the implementation phase, no employee engagement or participation techniques were mentioned besides the feedback from the business unit during the pilot run. Also, not in every business context do the process workers have IT-related skills or are interested in taking over more IT-related tasks and becoming Business Unit Developers [23]. However, the findings also highlight challenges related to employee acceptance and perception of RPA. Some employees express concerns that the implementation is an attempt to replace them or view the consultants involved as strangers working to eliminate their positions. Factors such as fear of change, personal energy costs, and the time required to adapt contribute to a relatively limited level of enthusiasm and acceptance among employees.

"*I have noticed that employees have a feeling that the boss wants to get rid of them. The employees consider us [consultants] as strangers who come to get rid of them. From three colleagues, then 2 stay [after the RPA project]. 'RPA robot is coming to replace me'. Or 'I actually want to do this task for another 20 years, I don't want to be transferred somewhere else'. Automation idea comes from management level, but employees are against it, you can tell."* (Interview partner 2, 00:58:40)

V. DISCUSSION AND OUTLOOK

The field of RPA is a relatively new area of research with few scientific works available on the topic. While the subject is becoming increasingly prevalent in industry, the majority of existing research has focused on the process management and performance side of projects. This study addressed this gap by examining the operation stage of RPA implementation, including the acceptance of the technology by process workers and their concerns in the handling of this technology. The presented research is in line with previous findings that successful RPA implementation requires business process analysis and optimization prior to implementation [19]. Also, the findings show that initiatives for implementing RPA tend to be driven by management or a central department within the enterprise, with the expectation of reducing costs, replacing human labor, and improving process quality. In addition, our study highlights the lack of employee involvement in the RPA implementation process, as well as the need for further research on the implementation of the aspects of process security and the maintenance of the introduced RPA-supported processes.

The limitations of this work are a limited number of interviews as well as the limited information that could be obtained from the process workers directly. Also, the interview partners were project members whose expertise is mostly limited on the RPA projects in the financial industry.

Future work in this field will focus more on the process worker competences and training. A maturity model of process actor participation in IT implementation and co-creation of the RPA-supported processes will be developed and evaluated. Suitable co-creation and participation methods need to be identified and evaluated to ensure an effective and efficient process support and maintenance with RPA technologies. Security aspects will be put into focus in the planning and implementation phase.

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Advancing Sleep Research through Dynamic Consent and Trustee-Based Medical Data Processing

Rodger Burmeister
FZI Research Center for Information Technology
Karlsruhe, Germany
ORCID: 0000-0003-1847-0003
burmeister@fzi.de

Christina Erler
FZI Research Center for Information Technology
Karlsruhe, Germany
ORCID: 0000-0002-1273-5587
erler@fzi.de

Friedrich Gauger
FZI Research Center for Information Technology
Karlsruhe, Germany
ORCID: 0000-0002-7416-7909
gauger@fzi.de

Raphael J. Dressle
Department of Psychiatry and Psychotherapy
Medical Center - University of Freiburg, Faculty of Medicine
University of Freiburg, Germany
ORCID: 0000-0001-9408-5196
raphael.dressle@uniklinik-freiburg.de

Bernd Feige
Department of Psychiatry and Psychotherapy
Medical Center - University of Freiburg, Faculty of Medicine
University of Freiburg, Germany
ORCID: 0000-0002-9436-1258
bernd.feige@uniklinik-freiburg.de

***Abstract*—Medical data obtained from individual sleep studies are of great value for scientific research. Yet in Germany, their use is often hindered by legal restrictions, problems with heterogeneous data landscape, and lack of standardized data formats and quality criteria. In this paper, we propose a pioneering architecture to remove these barriers. Our distributed setup ensures that sensitive data remains within the secure boundaries of the originating institutions while patients have control over the subsequent use of their anonymized data. At the heart of our approach is the concept of a data trustee, providing easy-to-use interfaces for the key stakeholders: data producers (sleep clinics), data recipients (researchers), and data providers (patients). We use the innovative concept of dynamic consent to update usage rights and conditions. By using containerized data processing and automated de-authentication, data usage requests are filtered through standardized metadata criteria across all connected data producers, ensuring both privacy protection and streamlined data selection. In addition, our system features tamper-proof logging to ensure transparency and traceability across all transactions. With this integrated approach, we aim to realize the full potential of sleep research while adhering to strict privacy standards and enabling seamless collaboration between stakeholders.**

***Index Terms*—data sharing; consent management; secondary use; health data; clinical data management; user interface design; sleep research; data trustee; software architecture.**

I. Introduction

Research in the field of sleep medicine plays a vital role in maintaining and improving human health. Given the complexity of sleep and its impact on numerous aspects of human well-being, the exchange of data collected during clinical standard patient care is crucial, especially for analyzing sleep disorders that occur infrequently. At present, the exchange of sleep research data in Germany is often affected by fragmentation, institutional data silos, bureaucratic barriers, missing transparency, inefficiency, and data quality issues [1]. Research institutions and clinics have a variety of data sources and formats that make it difficult to use and share this data effectively. This leads to a suboptimal use of available resources and hinders progress in sleep medicine as a whole. Consequently, there are several initiatives [2] [3] and research endeavors in Germany aimed at addressing these challenges that currently do not consider the context of sleep medicine. International efforts are underway in sleep research, with databases like SIESTA [4], PhysioNet [5], and the National Sleep Research Resource (NSRR) [6] offering access to polysomnography data, albeit with variations in accessibility, topicality, and usability. While SIESTA is not publicly accessible, PhysioNet and NSRR are curated and freely available but vary in usability, needing clarification case by case. No openly accessible databases are known from Europe.

In this regard, data trust models [7] are a promising solution that enables the secure exchange and secondary use of clinical research data. By introducing trustee entities that act as trustworthy intermediaries between patients, clinics, research institutions, and other stakeholders, privacy concerns can be addressed, and access to sensitive data can be improved across institutions. Trustee models not only provide a framework for secure and privacy-preserving data sharing but also potentially promote transparency and fairness in the handling of medical research data.

Despite the potential of data trust models, various challenges remain in practice. These include issues relating to the self-determined handling of patient data, data security and integrity, compliance with legal regulations, such as the General Data Protection Regulation (GDPR) [8], and promoting trust and collaboration between the stakeholders involved. Patients, research institutions, clinics, and trustees must work together to overcome these cross-organizational challenges and ensure sleep medicine research data's effective and ethical use.

In this paper, we present a digital trustee model architecture for a dynamic, patient-centered sharing of medical sleep research data that contributes to the meaningful secondary use of this data and the establishment of data donation cycles [9]. Our

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architecture addresses various challenges and stakeholders' perspectives, lessons learned in the conceptualization and prototypical implementation of such a trustee architecture, and insights into how data trustee models can support data sharing in sleep research. By taking a holistic view of these topics, we hope to provide insights that contribute to developing effective strategies, processes, and information technology (IT) systems to improve data sharing in sleep medicine.

Section II outlines the methodology for designing, implementing, and assessing a trustee platform for sleep research in Germany. Following this, Section III explains the platform's architecture, dynamic consent procedure, and researcher interactions. Section IV covers the evaluation approach and findings, concluding with a discussion on their implications in Section V.

II. Methodology

An interdisciplinary approach was adopted to devise a robust data trust model for the secure management and effective utilization of medical data in German sleep research. Collaborating with clinical personnel, IT specialists, researchers, data protection officers, and ethicists, a comprehensive concept was formulated and iteratively refined. This concept prioritized offering patients and researchers a user-friendly platform that could integrate into existing clinical workflows while ensuring strong data protection measures.

Initial interactive user interface (UI) mockups were developed for patients and researchers in the subsequent phase. These mockups were subjected to evaluation by a small cohort of patients and researchers, assessing trustworthiness, usability, functionality, and aesthetics through a structured questionnaire. The insights gained from this initial evaluation were crucial in shaping the development of a functional prototype. The prototype underwent further scrutiny and refinement, culminating in its presentation to patients, researchers, and domain experts. Utilizing identical questionnaires, the final evaluation aimed to establish comparability between the initial interactive mockups and the fully realized data trustee prototype.

This iterative methodology, integrating stakeholder feedback at various stages of development, ensured the alignment of the final prototype with the envisioned objectives of usability, trust, clinical integration, and data protection.

III. Technical concept and design

A. A distributed architecture for data trustees

Two significant challenges faced in crafting an architecture for a data trust system within the realm of sleep medicine are:

- **Liability concerns:** Given the sensitive nature of patient data, complying with strict legal regulations for handling patient data is a daunting hurdle for clinics in Germany. Direct disclosure of or access to data by third parties is a major challenge due to legal restrictions and liability concerns.
- **Rule enforcement:** Practical monitoring of data protection and data trustee compliance in research projects is a major challenge for trustees. Patients and clinics need a solid level of protection to have confidence in the trustee, even if the data is anonymized.

A monolithic architecture in which medical data is kept centralized and passed on directly to research projects, even with patient consent, proved to be incompatible with these requirements. In our work, we opted for a decentralized, distributed trustee system architecture, as depicted in Figure 1. The architecture follows the C4 model notation [10], focussing only on essential system components for clarity.

We identified four key stakeholders within our trust system: data providers (patients), data recipients (scientists), data producers (clinic staff), and data trustees (platform operators). Each interacts with the data trust system and requires a specific, user-friendly interface to fulfill its role. Single-page web applications, hosted on scalable application servers by the trustee, deliver tailored user interfaces for each role. This setup ensures accessibility and operability across various end devices. Notably, components of the trustee platform operate not only on the trustee's infrastructure but also within clinical infrastructures. This complies with German clinics' strict data security obligations and their reservation regarding data transfer to third parties. In this architecture, adapter services run distributively in participating clinics, linking patients' trust account IDs to their medical records on the clinic side and facilitating anonymized data access per request. Control over the provision of and access to anonymized data remains with the clinic. For research analysis, the trustee's application server aggregates anonymized data and executes analysis scripts within a controlled container environment in the trustee's data center. The results are then reported back to the researcher. Our prototype leveraged Curious Containers [12] for controlled execution, tailored explicitly for scripted experiments. Upon analysis completion, aggregated data is promptly deleted from the trustee's servers, although metadata required for search queries may be cached for efficiency. Access to anonymized patient data by researchers is logged alongside executed scripts and results in a tamper-proof database. This logging simplifies subsequent checks in the event of suspicion and reduces the risk of misuse. While controlled execution environments do not entirely negate abusive behavior, logging significantly raises the bar.

In conclusion, our architecture provides clinics with comprehensive data control, seamless integration into clinical workflows, and secure analysis without exposing clinical record data to researchers. However, it may entail reduced flexibility for researchers in direct data handling and increased computing resource demands for analysis scripts executed on the trustee platform.

B. Empowering patients with dynamic consent

Designing an informed consent process for patient-centered data sharing in sleep research posed several key challenges:

- **Comprehensive understanding:** Ensuring patients understand the risks and benefits of data sharing without struggling with lengthy, complex documents.

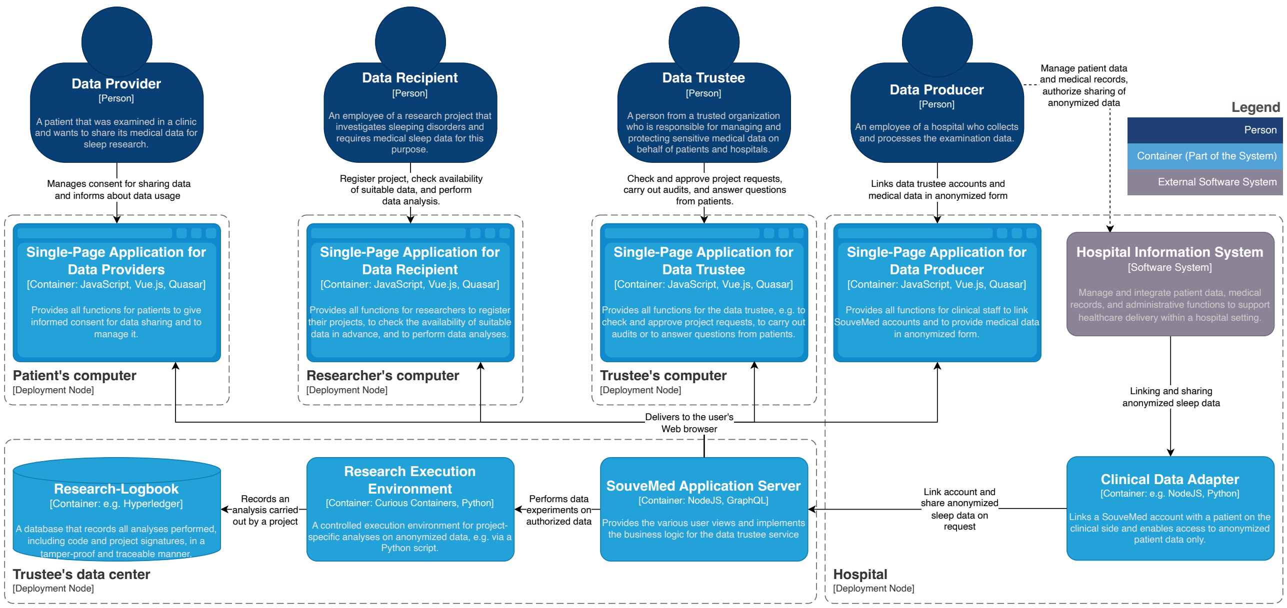

Fig. 1: A C4 model container diagram describing the data trustee's distributed architecture with its essential building blocks. The light blue blocks are part of the system. The dashed boxes describe the different deployment nodes.

- **Flexibility and control:** Providing patients greater autonomy in managing their data compared to traditional broad-consent methods.
- **Data granularity:** Balancing the level of detail for controlling data access to avoid overwhelming patients while still providing meaningful control.
- **Duration and withdrawal:** Facilitating easy withdrawal of consent and managing the duration in line with administrative burdens for data usage.

In current clinical practices in Germany, broad consent is the preferred method, often obtained through lengthy written, legally sound forms [13]. Patients commit to long-term use of pseudonymized data for clinical research, requiring a careful read of extensive information sheets. While revocation is feasible, modifying consent details post-signing is often impractical. In contrast, when developing a data trust platform for sleep medicine, we opted for a dynamic consent approach [11] that improves the process of consent for patients in three ways:

- **Personal consultation:** Patients are informed about the shared use of data in a personal conversation during the clinic visit, which makes it easier to understand the digital information sheet later.
- **User-friendly app:** A dedicated app empowers patients to self-inform, manage consent dynamically, and engage with the process conveniently.
- **Coarse granular data management:** Patients can manage their data records at the level of clinical stays, facilitating ease of control and understanding.

During the clinic visit, patients are briefed on data-sharing risks, opportunities, and procedures, with ample room for discussion. Subsequently, patients can establish a personal data trust account via the trustee platform using their devices. Consultation with their physician allows linkage of their trust account ID to clinical data. Following pseudonymization, patients gain access to and control over their stay data via the app. The consent process involves two steps: (1) confirmation of a digital information sheet and (2) explicit selection of pseudonymized data records for sharing, as illustrated in Figure 2. Patients must confirm their understanding of risks and opportunities before choosing data records and specifying project access preferences. For instance, patients have the option to specify whether access to the data records should be limited to non-profit endeavors or extended to commercial projects. Additional preferences, such as notification preferences for incidental findings, are also indicated.

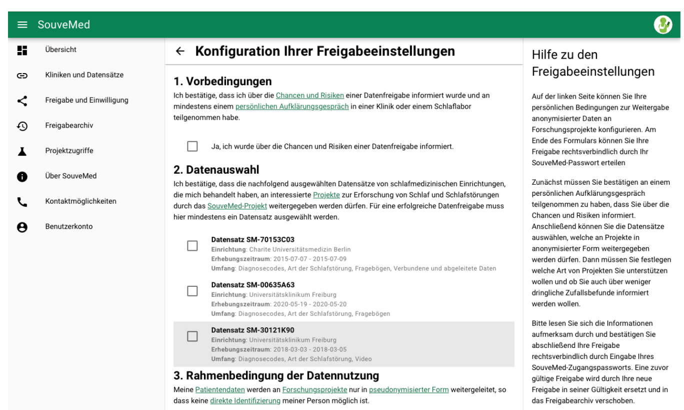

Fig. 2: Tailoring data sharing preferences through an intuitive user interface in the trustee application.

Upon confirmation with their account credentials, data is made available for project requests according to the specified settings. Patients can monitor shared data, associated projects, and responsible parties at any time, with the flexibility to adjust

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or withdraw consent as needed.

Our process ensures transparency and patient empowerment, a departure from conventional broad-consent practices. Initial consultations and digital consent forms featuring video aids and supplementary texts democratize access to modern trust systems in sleep medicine. Combining personalized clinic consultations and intuitive digital consent mechanisms fosters patient-centered data management, promoting transparency and autonomy in sleep research endeavors.

C. Secure data requests and analysis for sleep researchers

There are currently two major systems in Germany that facilitate the request and utilization of research data from the healthcare sector for third parties, which themselves go beyond the stage of being research projects. The Health Data Lab (HDL) at the Federal Institute for Drugs and Medical Devices [2] exclusively permits the on-site and off-site use of billing data and statistics from the statutory health insurance funds but does not extend to routine healthcare or research data. Another noteworthy system is the German Portal for Medical Research Data developed by the Medical Informatics Initiative (MII) [3]. However, this platform presently grants access only to public researchers. Moreover, despite the existence of a central platform [14] for data requests, individual legal contracts must be established subsequently with each data-providing institution, complicating the process [15].

In addition, the amount of available data varies depending on the analysis type. For example, while the MII enables centralized and distributed analysis of pseudonymized data, the adoption of broad consent in German healthcare remains limited, restricting the data accessible for centralized analysis. Moreover, distributed analysis is currently limited to R statistics scripts and does not include machine learning approaches. As the platform is still under development, with only university hospitals connected for the most part and many sub-steps still undergoing manual verification, the number of processed data uses has been limited since its activation in May 2023. In addition to these platforms, which are doing pioneering work with regard to the use of research data in Germany, access to medical data and its utilization is currently often perceived as laborious according to a survey of Erler et al. [15].

Considering these findings, the main obstacles in designing a secure data request and analysis process include:

- **Data governance:** Establishing a central point of contact for legally compliant data requests and utilization despite decentralized data storage across various sleep medicine facilities proves challenging.
- **Data privacy and security:** Balancing the protection of sensitive health data and personal information, ensuring access only for authorized users, and taking into account the specific conditions for secondary data use by data providers and producers involves a tradeoff between protecting the privacy and autonomy of patients and in-depth data analysis.
- **Data quality and interoperability:** Standardisation issues in data and infrastructures, alongside varying data quality and formats, hinder proper analysis.
- **Scalability and performance:** Ensuring scalability and performance while maintaining data security and privacy is a balancing act.
- **Transparency and reproducibility:** It takes much effort to ensure that all relevant data, methods, tools, and parameters are accurately documented and transparent for authorized users.

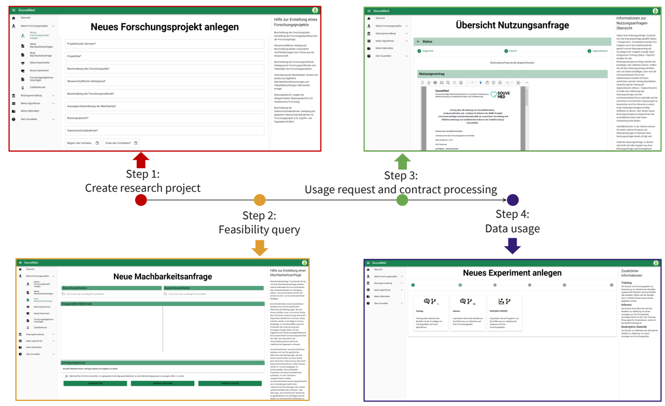


Fig. 3: The streamlined request process involves project registration, pre-checking data availability, requesting access, signing contracts, and finally, utilizing the data.

In order to increase the acceptance of the request processes by the data-providing institutions, the currently established MII processes for requesting data are used as the basis for our work. With this in mind, the four steps outlined in Figure 3 are supported in our process: (1) research project creation, (2) feasibility query, (3) usage request and contract processing, and (4) data usage.

As a first step, researchers must outline a research project with its objectives and purpose of data use. Subsequently, a feasibility query assesses whether the decentralized data trustee has sufficient data to address the project's research questions, incorporating various inclusion and exclusion criteria. Our feasibility query form is based on the design of the MII [16]. The design was extended to constrain the specific type of sleep medicine data required, e.g., for specific questionnaires or polysomnography recordings.

The use of standardized data descriptions based on the *Fast Healthcare Interoperability Resources* (FHIR) standard [17] in combination with FHIR Search [18] facilitates our feasibility queries. Notably, our work introduces standardized descriptions of sleep data (e.g., questionnaires, diagnoses, metadata on sleep medicine recordings such as polysomnographies) using FHIR resources, an aspect not currently addressed by the MII.

Furthermore, we introduced a matched-pairs functionality wherein each test subject is paired with a control subject matching certain influencing factors (e.g., age of ±3 years). Once sufficient data is available, researchers can submit a data usage application akin to the MII's data usage application form [16]. Pre-existing entries from saved research projects and feasibility queries can be directly incorporated into a request to streamline the process. After a legal review by the trustee and a successful contract conclusion, the de-identified data becomes accessible for research experiments. Researchers can upload and utilize machine learning or statistics scripts as well as existing machine learning models for their experiments. Post-experiment, results can be downloaded, and incidental findings can be reported back to treating physicians to ensure patients' well-being. In addition, unique dataset IDs can be publicly shared with other researchers to improve the reproducibility and transparency of results.

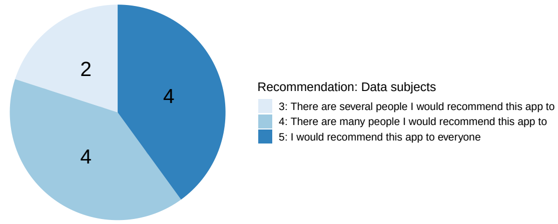
Overall, we used the following approaches in our proposed process to make data requests and analysis more secure, simple, and transparent:

- Establishing the data trustee as a central contractual partner for legally compliant data requests and usage of pseudonymized sleep data from diverse facilities.
- Standardizing sleep data descriptions using FHIR resources.
- Implementing software adapters as uniform interfaces to existing heterogeneous systems in sleep clinics.
- Facilitating collaboration and data sharing between researchers and data producers while protecting data privacy and security and considering their individual conditions for secondary use.
- Designing a user-friendly platform with clear governance policies and streamlined procedures.
- Ensuring the reproducibility of research experiments through unique data set IDs and container-based execution environments.
- Providing a priori availability checks for relevant data without initial contracts, balancing data providers' privacy needs and data producers' business interests.
- Supporting common data usage types, including descriptive statistics and machine learning.
- Enabling data access for both public and private research institutions.
- Enabling reporting of incidental findings without overwhelming data producers or revealing their identities.
- Tamper-proof logging to simplify subsequent checks in the event of suspicion and reduce the risk of misuse.

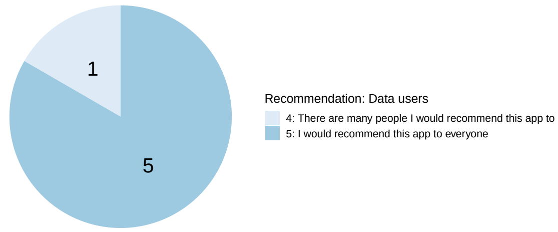
IV. Evaluation of Data Sharing and Trustee Model

A. Aims and methods

Our evaluation study aimed to assess the proposed data-sharing process and trustee model from the perspective of data subjects, data users, and representatives from data-generating institutions. To this end, we conducted an anonymous survey using online questionnaires. Key elements of the survey comprised the usability of the system, as measured by the user version of the Mobile Application Rating Scale (uMARS) [19], [20] and data subjects' trust, as measured by the Human-Computer Trust Scale (HCTS) [21]. The HCTS consists of 12 items that must be answered on a 5-point Likert scale from 1 ("strongly disagree") to 5 ("strongly agree"). For the uMARS, three out of four sections were presented to the participants: functionality, aesthetics, and subjective quality. One section was excluded from the survey to avoid overlap with other parts of the questionnaire. Responses were provided on a 5-point Likert scale, with higher values indicating greater subjective usability.



(a) Results from the survey of data providers (subjects). No data provider selected the first two response options.



(b) Results from the survey of data recipients (users). No data recipient selected the first three response options.

Fig. 4: Results for the recommendation item of the end user version of the mobile application rating scale (5-point Likert scale).

B. Results

The final prototype was evaluated by 10 data providers (patients) and 6 data recipients (research experts). Data providers demonstrated a high level of trust in the proposed concept, with a mean HCTS score of 4.28 (± 0.80). Functionality was rated highly by both data providers, with a mean rating of 4.50 (± 0.81), and data recipients, with a mean rating of 4.58 (± 0.52). Similarly, aesthetics received favorable ratings, with data providers averaging 4.23 (± 0.96) and data recipients averaging 4.17 (± 0.71). In terms of subjective quality, a majority of both data providers and recipients expressed their likelihood of recommending the system to potential beneficiaries (see Figure 4).

V. Discussion and Conclusion

Addressing the manifold challenges of establishing a data trustee system in the context of sleep medicine requires a comprehensive approach that considers the needs of all stakeholders involved, ensuring both secure and ethical data sharing and use. Our research demonstrated that introducing a user-friendly data trustee app combined with personalized consultations enhances patients' comprehension and engagement in data sharing. A central and trustworthy intermediary seems to give patients the perception that they are cared for and that their data interests are prioritized in line with the GDPR, as demonstrated in our evaluation study by the high level of trust regarding the proposed system. This finding is consistent with studies emphasizing the key role of appropriate communication and involvement of data providers in building trust [22] [23]. Also, our coarse granular data management approach empowers patients to maintain significant control over their data, giving them greater autonomy and sovereignty in the data-sharing process compared to approaches based on broad consent. In addition, the feeling of being asked and taken seriously as a data provider is strengthened. Furthermore, we have developed a digital consent and administration process for data providers as a possible alternative to the current paper-based processes used in German initiatives. From the perspective of data recipients, we have mapped out a digital process incorporating data availability queries, data requests, contract processing, as well as scientific and incidental reporting. Both from the perspective of data providers and data recipients, our evaluation found that the developed system offers good usability, which is crucial for the acceptance of the system. In addition, both data providers and data recipients benefit equally from the legally secure framework offered by a data trustee, which in turn reduces the barrier caused by legal uncertainties. Our proposed platform consolidates all these features into a single system, providing researchers with a centralized digital hub unlike any existing systems.

In addition, we are the first in Germany to describe domain-specific data related to sleep laboratory stays for secondary use through FHIR resources, aligning the concept of a data trustee with FAIR data principles (Findable, Accessible, Interoperable, Reusable). By employing standardized data descriptions combined with robust security measures, we ensure both privacy and interoperability, facilitating collaboration between researchers and sleep clinics. Moreover, the implementation of tamper-proof logging enhances the traceability and detection of data misuse, thereby reinforcing ethical data practices in sleep medicine research.

However, it is essential to acknowledge the limitations of our work. The sample size of 16 participants across all user groups may only represent a part of the user population, potentially limiting the generalizability of the study findings. Nevertheless, by acquiring initial impressions in the specific sleep medicine use case, we have gained valuable insights and outlined preliminary solutions for addressing design challenges in data trust systems, laying the groundwork for further research. Through the adoption of a decentralized, distributed trust system architecture, we have showcased the potential of a socio-technical data trustee system as a neutral intermediary that fosters trust and collaboration among stakeholders in the field of sleep medicine, enabling a fair balance of interests and facilitating a trustful exchange and secondary use of data.

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Beyond Connectivity: A Sustainable Approach to Municipal LoRaWAN Infrastructure and Services

André Nitze
Department of Business
Brandenburg University of Applied Sciences
Brandenburg an der Havel, Germany
e-mail: andre.nitze@th-brandenburg.de

Josephine Jahn
[Sustainability –Transformation - Transfer] Research Center
Eberswalde University for Sustainable Development
Eberswalde, Germany
e-mail: josephine.jahn@hnee.de

Tingting Wang
Department of Business
Brandenburg University of Applied Sciences
Brandenburg an der Havel, Germany
e-mail: tingting.wang@th-brandenburg.de

Sabah Ali
Department of Business
Brandenburg University of Applied Sciences
Brandenburg an der Havel, Germany
e-mail: sabah.ali@th-brandenburg.de

***Abstract*—Long-Range Wide-Area-Networks (LoRaWANs) are distinguished by their capability to support Internet of Things (IoT) applications, making it ideal for vast and sparsely populated areas. While technical features like security, scalability, and bandwidth have been examined in detail, forms of collaboration between stakeholders have yet to be explored. Hence, we introduce the LoRaWAN Collaboration Framework (LCF), a blueprint for deploying and managing LoRaWAN infrastructures with an emphasis on rural and small municipalities. The LCF aims to address common challenges in these settings, such as limited technical expertise, financial constraints, and the need for cross-municipal cooperation. It outlines roles and responsibilities across various stakeholders including municipal authorities, Information Technology (IT) service providers, application developers, and end-users. The framework emphasizes the balance of technological, economic, ecological, and social sustainability. We describe the experiences from several LoRaWAN projects in small towns and municipalities in Germany and the derived collaboration framework to provide a basis for similar projects.**

Keywords-LoRaWAN; Service delivery; collaboration; sustainability; smart city; infrastructure.

I. INTRODUCTION

Sustainability and efficient resource utilization is an indispensable reality of today's world. To meet these sustainability goals, a transformative shift towards advanced digital technologies is essential, emphasizing the role of digitalization in enhancing environmental, social, and economic outcomes. Cities may tackle this demand with the help of IoT technologies. LoRaWANs are a big contribution in this development, as their range and costs are well-suited for providing a network infrastructure for smart city applications in rural areas.

LoRaWAN provides wireless data transmission that is comparable to Wi-Fi and Bluetooth but has its own distinct properties. LoRaWAN is a low-power wide-area network (LPWAN) technology that facilitates communication of connected devices covering long distances while consuming low energy [1]. This makes LoRaWAN particularly suitable for rural areas and regions with large areas and limited electrical energy, such as developing countries. The LoRa Alliance developed LoRaWAN specifications, whose basic modules are available as open-source software [2].

LoRaWAN is an enabler technology [3] that can not only help achieve the Sustainable Development Goals (SDGs) by measuring climate impacts, modal split, soil moisture, sealing, water levels et cetera, but it also allows for automating and initiating counter measures, for example to save CO2-binding trees, moorland and so on.

Although demand is growing, the construction, data integration, processing and visualization required for an end-to-end LoRaWAN use case can only be done by technical experts, and small cities and local governments cannot do it alone. This group lacks basic technical knowledge and has insufficient human resources – in particular IT staff. Moreover, there are only limited financial resources available for digitalization. Hence, many projects concerning IoT or "smart city" are conducted using third party funding (public or private) instead of household budgets, or not at all.

Despite the urgent need for climate adaptation at all levels, the willingness of small towns and municipalities to contribute to climate goals, and the relatively low cost of LoRaWAN, in many cases this is not enough to build technically and organizational sustainable LoRaWAN infrastructures in these regions. This raises the question of a common operating model for LoRaWAN in rural areas, for example across several small towns and municipalities. This would demonstrate efficiency and cost benefit (cost savings, volume benefits, and production efficiencies) to be attained that would make a business economically viable. That can only be achieved if all the required actors have clear areas of responsibility and associate the LoRaWAN infrastructure with a benefit for themselves.

There is a clear need for a framework that:

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- defines responsibilities for different stakeholders in LoRaWAN projects,
- balances ecological, economic, technical, and social objectives, and
- enables local authorities and municipalities to operate LoRaWANs in the long term.

Therefore, in this paper, we propose the LoRaWAN Collaboration Framework (LCF), which addresses and tries to solve these issues.

The rest of this paper is organized as follows. Section II describes the related work in the areas of sustainability and LoRaWAN service management. Section III describes how we gained our findings. Section IV describes the framework including the responsibilities of the various stakeholders and the organizational interfaces. The conclusions close the article.

II. Related Work

Due to its impact on the economic and social sphere, digitalization is no longer seen as an isolated technical phenomenon. Digitalization as an encompassing process is related to massive changes in the economic production, in communication patterns and in other social aspects of everyday life and therefore has an influence on the society. Nölting and Dembski found that digitalization, as a process, has no normative direction, but, in contrast, is governed by individual and organizational entities in accordance with their own goals [4]. Digitalization technologies, such as LoRaWAN provide many opportunities, which can or cannot be used in terms of sustainability in its diverse dimensions.

According to Farsi et al. [5], sustainability is important to maintain the basis for sustainability assessment. While sustainability is generally accepted as an important goal in our time, it is important to clarify the meaning and the different dimensions of the term sustainability as used here. In accordance with the current understanding in the scientific community, we consider the three dimensions of sustainability [6]: economic, environmental or ecological, and social sustainability. We also consider technological sustainability an important factor of sustainability and will discuss it as well.

A. Technological sustainability

Sustainability of technology in the past has been mostly focused on green IT, while more recent research, for example by Dao et al. [7], demonstrates a more holistic approach. For LoRaWAN projects, it means that the IT infrastructure can be used and maintained in the long term and does not require extensive adjustments in its foreseeable life cycle. No matter who is developing it, a sustainable combination of software technologies that are used together (i.e., "tech stack") should therefore be beneficial in the long term. A requirement for this is the availability of code and documentation under permissive licensing, as it is common for open-source software.

Technological sustainability also includes a reference data model for a clear database that is compatible with data from other municipalities. Such a data model would have to define which data is recorded by which sensor in which configuration. Even with seemingly straightforward devices, such as soil moisture sensors, various critical factors—such as the depth of installation, soil type, measurement intervals, and calibration—significantly affect the data obtained. Moreover, it delves into the data's transformation processes throughout its lifecycle, including storage practices (data lineage), the mechanisms of data provision, and its semantic description. Finally, the integration of the data into broader metadata portals is essential for maximizing utility and accessibility. Adding metadata can increase data quality and allow the data to be used outside the original measurement context, e.g., to create dashboards to monitor and improve the SDGs at a local level.

B. Economic sustainability

Ikerd defines economic sustainability as scarcity, efficiency, and sovereignty [8]. To increase the economic sustainability, private and public companies, universities, and colleges should contribute their knowledge and services. It is important to process the division of labor.

Economic efficiency and thrift often meet each other, for example when reduced consumption of resources and energy correspond with lower financial costs. Sustainability in terms of economy also refers to long-term usability of investments. In the case of building a LoRaWAN infrastructure, a municipality must be convinced that the benefit will exceed the costs of its implementation (economic viability). This can be achieved, for example, by reducing personnel costs for manual reading of measured values and other routine activities that can be automated using actuators and sensors.

C. Ecological sustainability

Ecological sustainability refers to the reduction of consumption and pollution of natural resources and energy as they are exhaustible fundamentals of social and economic life, according to Beer et al. [9]. To preserve the (ecological) basis of living for future generations on earth is the core definition of sustainable development as defined by the United Nations [10]. LoRaWAN technology can be used for the protection of natural resources, for example in the field of environment data measurement. For example, solar panels can power remote gateways, reducing the system's carbon footprint. Infrastructure can be installed in locations that minimize environmental disruption, using existing structures where possible to avoid additional land use and ecological disturbance.

D. Social sustainability

The last dimension of sustainability considers that social equity and cohesion are further indispensable for a sustainable development. Social sustainability refers to equal opportunities for "good living" and participation in the society for every individual [11]. About LoRaWAN technology in municipalities, the participation of citizens can be strengthened by promoting citizen science projects to utilize the collected data for their own needs or to improve the local provision of public services.

A socially sustainable LoRaWAN model prioritizes accessibility, benefits all segments of society, and fosters

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positive community impacts. For example, low-cost connectivity and easy deployment foster the development of local solutions that address specific local challenges, such as agriculture, healthcare, education, and environmental monitoring. Robust data protection measures must be in place to safeguard user privacy and enhance trust in LoRaWAN services. To tailor LoRaWAN installations to the needs and priorities of the community, collaboration with local authorities and community groups is required.

The three dimensions of social, ecological, and economic sustainability are all part of the sustainable development approach. Consequently, they are all represented in the 17 Sustainable Development Goals of the United Nations [12]. The challenge for practitioners is to find integrated solutions to achieve these goals in a holistic way.

E. LoRaWAN Service Management

Information Technology Service Management (ITSM) is a process-focused discipline that is concerned with the efficient and structured delivery and support of IT services [13]. While the concept and its popular implementation, the IT Infrastructure Library (ITIL), have long been known and practiced, no work could be found examining the application of service management principles to the LoRaWAN realm.

LoRaWAN sensors and smart city applications have been thoroughly compiled by Bonilla et al., Campoverde and Yoo [14]. The contributions edited by Song et al. [15] as well demonstrate the breadth of smart city and IoT applications, but also the need for sustainable operating models and service management.

Zanella et al. [16] found that smart city projects can be complex due to heterogenous technology (wireless transmission standards, sensors, software architecture), many different use cases, and the integration of data sources and sinks to make possible diverse digital services.

However, most of these findings are based on case studies in larger cities. No research could be identified that is concerned with LoRaWAN infrastructure for small towns and rural areas with low population density that still want to leverage the technology.

III. METHOD

We draw our experience from several projects in Germany in which we established LoRaWAN infrastructures, deployed sensors of different types, and created data visualizations. We synthesized our findings from projects in the municipalities Michendorf, Rüdersdorf, and Wiesenburg, and the town Brandenburg an der Havel.

The municipalities are nearby and have contacted us following initial reports of successful deployments. We therefore assume that these are municipalities that are consciously seeking to drive digitalization forward. In some cases, we have already come across acquired funding or ongoing smart city efforts.

Table I illustrates the details of the covered sites. All projects deal with "technology transfer" in the sense that the university research team applies their knowledge and skills to practical problems of local companies and municipal administrations. Some of the projects are still ongoing, so findings might not be conclusive. Areas of application of the different projects include soil moisture, water temperature, water level, parking spots, presence detection, people counting, and traffic counting.

After clarifying project goals and scope, the project team selected and configured appropriate gateways, sensors, and data visualization platforms. The town or municipality then usually installed the configured sensors themselves. However, a large part of the project durations was spent coordinating with various project participants, organizing site visits, and waiting for service providers, key supporters from within the administration, or decision makers to clarify responsibilities. We had to explain to authorities and network operators that the technology is safe and will not interfere with other radio equipment. Site visits usually took a lot of planning and alignment due to the various ownership structures of buildings, in particular, towers and other tall structures that are already used for other purposes, e. g., sirens and webcams of fire departments, air traffic beacons, and other radio cell systems.

TABLE I. OVERVIEW OF PROJECT SITES

Site	*Population*	*Pop. density (people per sq. km)*	*Time frame*	*Deployment*
Brandenburg an der Havel	72,100	320	2022-2024	12 gateways, 25 sensors
Rüdersdorf	15,500	228	2024	2 gateways, ~10 sensors
Michendorf	11,600	202	2023	2 gateways, 38 sensors
Wiesenburg	4,900	19	2022-2024	4 gateways, 30 sensors

Funding has been and is a crucial part of every project. Limited short-term funding is usually available, particularly for the procurement of sensors. Due to the way public budgets are planned, there is rarely a permanent funding option for LoRaWAN projects. These are often seen as one-off digitization or technology evaluation projects.

As part of these endeavors, we had frequent talks with all involved stakeholders, such as the municipal administrations, regional utilities, private network suppliers and end-users from other areas, such as citizen science and climate initiatives. By accompanying and promoting these processes we learned not only that LoRaWAN projects tend to face similar difficulties in different places, but also that there are many similarities in the needs and capabilities of the stakeholders involved.

Analyzing and conflating these learnings led to the creation of an operational template for LoRaWAN infrastructure and services. This framework names the individual actors, as well as their tasks, or responsibilities, in the process of establishing said infrastructure to meet all requirements of the participating stakeholders and especially the end-users.

IV. LORAWAN COLLABORATION FRAMEWORK (LCF)

The LoRaWAN Collaboration Framework (LCF) serves as a blueprint for effective stakeholder collaboration in the deployment and maintenance of sustainable LoRaWAN infrastructures for communities. It delineates the roles, responsibilities, and necessary capabilities for each participant, ensuring that all involved parties understand what is required of them and what they need from others. This clarity facilitates not only the identification of existing and potential contributors to the LoRaWAN ecosystem but also the establishment of seamless interfaces and partnerships. By highlighting specific needs and capabilities across stakeholders, the LCF aims to streamline operations, foster innovation, and enhance service delivery and citizen engagement.

A. *Framework structure: Roles, needs and capabilities*

Fig. 1 illustrates the structure of the LCF and provides details on each role. The stakeholders are grouped by “infrastructure” and “application”. The infrastructure group is mainly concerned with deployment, operation, and maintenance of the hardware, software, and networking infrastructure. The “application” group deals with the implementation and customization of software and data platforms, deployment of sensors, and the direct application of technology to solve practical community problems. Stakeholders take on at least one role in the LoRaWAN ecosystem. The interaction of all roles and the correct distribution of tasks is critical to the success of LoRaWAN projects.

To define each role, the framework is split into “wants and needs” (top row) and the “capabilities” (bottom row) of stakeholders. This alignment ensures that the capabilities of one group meet the needs of another, facilitating a symbiotic relationship that enhances the efficiency and success of LoRaWAN projects.

By strategically aligning roles along a spectrum from technological infrastructure (left) to end-user applications (right), the LCF ensures effective utilization of each stakeholder’s capabilities, fostering cooperative dynamics across the ecosystem. This structured approach helps stakeholders like network operators serve multiple municipalities, which can share best practices and collaborate on common sustainability goals. The roles are briefly described in the following.

1) *Network operators and utility companies*

Network operators and utility companies are driven by goals of market expansion and the development of new revenue streams. These stakeholders are adept at providing sites and connectivity for gateways, managing LoRaWAN Network Servers (LNS), and conducting essential on-site maintenance, such as battery replacement and cleansing of sensors.

	Infrastructure		**Application**		
	Network operators and utility companies	Hosting and IT service providers	Start-ups, universities, and specialized IT companies	Administrations	End-users
Wants & Needs what stakeholders want and need	• Market expansion • New revenue streams and business models	• Stable contracts and partnerships • Maintainenance-friendly software components • Opportunities to showcase and deploy new technologies • Support by hardware and software vendors	• Evaluating cutting-edge technology • Funding for R&D or transfer projects • Partnerships • Visibility and recognition	• Education on technology options • Fast and efficient delivery of services to citizens • Enhanced citizen engagement and satisfaction • Limited Total Cost of Ownership (TCO) • User feedback on provided services	• Convenient access to municipal services • Intuitive interfaces and good user experience • Integration with other IT systems • Security features to protect user data and privacy • Regular updates and improvements
Capabilities what stakeholders are able to contribute to the LoRaWAN value chain	• Provide sites and connectivity for gateways • Operate the LoRaWAN Network Server (LNS) • On-site servicing of sensors (batteries, cleansing, replacement)	• Provide computing resources (hardware, software, virtual machines, and networks) • Install and configure standard software packages • Configure sensors • Backups & security • Customer support and training for municipal staff and end-users	• Build innovative prototypes • Find or build the right sensors for use cases • Develop custom software • Integrate custom data sources and platforms • Create machine learning models • Support and train end-users	• Problems / use cases • Provide sites for gateways • Deploy sensors • Budget or funding for public IT projects • Collaboration with private entities and other government agencies	• Problems / use cases • Give feedback on services

Figure 1. LoRaWAN Collaboration Framework (LCF) with stakeholders and their responsibilities within LoRaWAN projects.

2) *Hosting and IT service providers*

On the technological service front, hosting and IT service providers aim for stable, long-term contracts and opportunities to deploy emerging technologies for their customers. They provide vital capabilities, such as the provisioning of computing resources, software installation, sensor configuration, and rigorous data security measures. Moreover, they can provide support and training for municipal staff and end-users, ensuring smooth operation and adoption of technologies.

3) Startups, universities, and specialized IT companies

In the innovation and research sector, startups, universities, and specialized IT companies are focused on evaluating and implementing cutting-edge technologies. These entities are key in building innovative prototypes, selecting, or creating appropriate sensors for specific use cases, and developing customized software solutions. They can also handle the integration of custom data platforms and are instrumental in developing advanced machine learning models to support complex data analysis and decision-making processes based on the collected sensor data, e.g., for predictive maintenance applications.

4) Administrations

Administrative bodies, such as municipal digital officers in town halls, Smart City managers, and economic development teams, play a crucial role in ensuring the efficient and cost-effective delivery of enhanced community services. They handle strategic planning and governance, including defining use cases for technologies like LoRaWAN, overseeing the deployment of sensors, and determining locations for gateway installations. These officials are key in facilitating collaborations with the private sector and other government agencies to secure funding and support for public IT projects. By aligning such technological deployments with broader municipal goals, these bodies work to improve city operations and enhance services provided to citizens.

5) End users

End-users, crucial to the success of the whole LoRaWAN value chain, include individual citizens, local businesses, and public institutions. These users require easy access to municipal services via intuitive and potentially mobile-friendly user interfaces, seamless integration with existing IT systems, and robust security features to protect their data and privacy. For citizens, this might mean improved traffic management and waste collection services. Local businesses could utilize data from LoRaWAN sensors for optimizing operational efficiency and reducing costs. Public institutions might use the technology to enhance facility management and public safety. Their ongoing feedback is instrumental in driving the continuous refinement and user-centered optimization of services.

B. Sharing and swapping responsibilities

Some capabilities in the LoRaWAN value chain can be provided by several stakeholders.

For example, providing sites for gateway installations might be a task a communal administration might want to contribute to in a project. However, ensuring long-term connectivity at the site via wired or wireless connections, having trained maintenance staff on standby in case of breakdowns, and having constant access to necessary equipment (lift trucks, spare parts, etc.) are things which network operators or utility companies have established processes for, resulting in lower cost and higher quality of service.

Another common example is the installation of affordable sensors by citizens configured on municipal or public LNS. The existence of tech-savvy communities and individuals can be considered a substantial benefit for any municipality or town. But it might jeopardize the long-term support of these sensors and by that, data quality. If administrations want to rely on the collected data, there must be some kind of alignment and trust between the two groups.

A last example illustrates another problem of voluntary work. When volunteers create custom data integration layers using Python or JavaScript, this “glue code” might not be documented as required, complicating maintenance and future extensions (e.g., a “temperature” attribute is added to the next sensor model). This also includes simple things like patch management and storage of access credentials.

The same goes for configuring dashboards, providing end-user training, integrating data sources, and creating machine learning models. All these tasks can be handled by different stakeholders with varying degrees of quality, cost, and availability. Initial interest in certain stages of the value chain by any one party does not guarantee that all the required tasks are fulfilled by the role. So, for a stable and sustainable operation, we recommend the responsibilities as defined in the LCF, or at most, one “column” away from the original stakeholder group.

In summary, although some capabilities might be taken over by another party than designated in the framework, generally, this hurts sustainability.

C. Business models

A solid business model is needed to sustain a LoRaWAN infrastructure and application ecosystem. The identified “wants and needs” indicate a demand in the market, while the “capabilities” are potential services which satisfy needs in one of the following elements of the value-chain.

1) Supply-side business models

One solution is renting out the network on a per-sensor and per-time basis, thus creating a very low barrier to market entry for customers and allowing for rapid adoption of the service. However, like free Wi-Fi, this might eventually become a commodity and network operators need to find other ways to generate revenue.

Network operators and suppliers can capitalize on existing infrastructures, such as data centers and network backbones, to gain a competitive edge. Additionally, revenue generation extends beyond network access fees to include value-added services like sensor commissioning. R&D stakeholders contribute by offering scientific and technical support, optimizing gateway placements, selecting appropriate sensors, and providing custom data integrations, visualizations, and project management, adding significant value to the LoRaWAN ecosystem.

Value, of course, is understood differently by different stakeholders. When compared to commercial projects, public projects are rather focused on social and ecological sustainability. This might mean making it possible for citizens to participate in local decision-making like defining speed limits, deciding on the desired quality of air and water, increasing comfort with digital services, or improving public health and safety.

In conclusion, the business model of the supply-side of municipal LoRaWAN projects today relies on forwardthinking administrations which actively seek to contribute to achieving the SDGs by using advanced technology like LoRaWAN. In the future, the collection of such data could become a legal requirement. Only then are more local authorities likely to look for joint operating models.

2) Demand-side business models

A shared operations model would be beneficial for small-scale deployments like the ones we described above. For example, a properly set-up LNS can easily process data packages from several hundred gateways. Each gateway is technically capable of supporting thousands of LoRaWAN nodes, i.e., sensors and actuators. Sharing the infrastructure costs would therefore be an obvious way to achieve sustainable funding.

The problem with this approach in a municipal setting is twofold. First, administrations need to align their demands and timing, and agree on a fair share of the (still) required funding. So, there is a cost for coordinating interested parties. Second, the infrastructure needs to be installed and administrated in the partnering regions by the same operator. When these challenges can be overcome, e.g., by applying systematic project and stakeholder management and finding a way to align the diverse interests, there is potential for a low-cost infrastructure that benefits all the stakeholders and thereby provides a holistic societal value.

V. CONCLUSION

Our research aimed to determine whether there is an effective operating model for municipalities to implement LoRaWAN projects successfully. The proposed LoRaWAN Collaboration Framework provides a robust foundation by delineating roles and responsibilities, enabling municipalities to engage with suitable partners like hardware vendors, utilities, and innovators from academia and startups.

A crucial insight from our study is the essential role of collaboration in the successful deployment of LoRaWAN in rural and smaller municipalities. Collaboration not only facilitates access to best practices but also helps pool financial resources, optimizing the acquisition of necessary infrastructure and partners. Our experience in technical project management across these initiatives has underscored the need for a more holistic approach to ensure sustainable LoRaWAN deployment.

Further research needs to be done on the economic viability of the described business models. In particular, the shared operations model and its organizational and coordinative prerequisites as well as the proper involvement of citizen initiatives and individual volunteers.

A comprehensive analysis on the overall project outcomes is needed to validate that the ecological, economic, technical, and social objectives are in the desired balance. Because some sustainability dimensions are hard to measure, it must always be carefully weighed up which use cases can realistically make improvements and which are just greenwashed fig leaves.

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Intergenerational Technology Codesign in Deprived Coastal Regions

Ray B. Jones, Rory Baxter, Marius N. Varga, Oksana Hagen, Amir Aly, Dena Bazazian, Alejandro Veliz Reyes, Swen Gaudl
The ICONIC project, Centre for Health Technology
University of Plymouth, Plymouth, PL4 8AA, United Kingdom
e-mails: Ray.Jones@plymouth.ac.uk, Rory.Baxter@plymouth.ac.uk, Marius.Varga@plymouth.ac.uk, Oksana.Hagen@plymouth.ac.uk, Amir.Aly@plymouth.ac.uk, Dena.Bazazian@plymouth.ac.uk, Alejandro.Velizreyes@plymouth.ac.uk, Swen.Gaudl@plymouth.ac.uk

***Abstract*— Many coastal and rural areas in Britain are deprived. This regional aspect multiplies the effect of digital exclusion for older people. Younger people in these regions can also be digitally excluded. Codesigning digital technologies, using the natural and heritage resources of such regions would address this, but is rarely done. We present our methods and preliminary results, half-way through a 30-month project to develop novel technologies in extended reality, underwater telepresence, digital social games, and artificial intelligence voice interfaces and to use these assets to tackle digital exclusion. We are taking an intergenerational approach, working with 35 partner organizations, some to identify possible technologies and others to help with recruitment. Between August and December 2023, we ran 5 extended reality and 3 underwater telepresence intergenerational codesign workshops with a total of 36 attendees (24 older (50+ years old) and 12 younger (16-30 years old) participants). Social games and voice interaction workshops started in early 2024. In total we aim to recruit 120 participants (80 older, 40 younger) and codesign four new technologies. We present our experiences in recruitment and workshops This has lessons for (i) other regions facing similar issues of digital accessibility, (ii) those codesigning novel technologies for older people, (iii) those working in extended reality, underwater telepresence, social games, and voice interfaces.**

Keywords- digital inclusion; codesign; coastal regions: extended reality; underwater telepresence; social games; voice interfaces.

I. INTRODUCTION

Older and younger people living in coastal and rural areas, such as Devon and Cornwall (D&C) in England, face significant health inequalities [1] [2]. Although most solutions often lie with politics and economics, the codesign of human-centered digital technologies that reduce inequalities and empowers an equitable digital society, is also imperative. Three types of digital equity exist: (i) digital connection – being able to access the same digital facilities and services as everyone else; (ii) digital employability – having an equal chance for jobs in the digital economy and (iii) digital enablement – using digital to have equal chance of participating in aspects of society otherwise denied.

The benefits of a digital society are not equally distributed across different demographic and socioeconomic backgrounds. For example, older people often do not use digital technologies at all, or only minimally due to inequity in digital connectivity and enablement [3]. Furthermore, while older people's links with community, resources and meaningful activities are essential in supporting health and well-being, these links are increasingly dependent on a digital connection, often meaning Digitally Excluded Older People (DEOP) are at risk of being engulfed by an additional sphere of exclusion. For Younger People (YP), digital employability equity is of greater concern with disparities in opportunities for digital employment and career aspirations.

In England, the most disadvantaged regions are often coastal, characterized by areas of low productivity and high deprivation. Traditional industries, such as farming, mining, fishing, and port activity, have all declined, with alternative, often high-wage digital sectors struggling to emerge, resulting in an exodus of younger skilled people. Those left behind, may be from poorer backgrounds, lacking secure and well-paid jobs, or a clear sense of career ambition. Disadvantaged regions need to use the assets they have to try to address these digital inequalities. In England, many coastal regions, including D&C, have social, environmental and heritage assets. While access to such cultural and environmental assets are known to improve health and wellbeing, equitable access is not always available to older people. And the converse is also true, that digital equity is important for the economy of 'left behind' coastal regions. Digital technologies are becoming essential in presenting and connecting with local culture. The cultural landscape together with community groups makes a cultural ecosystem that gives a region its unique identity, helping to promote its economy to the outside world [4].

Technology for intergenerational connectivity is an emerging field [5]. Lack of technical support is often the main contributor to digital exclusion among older people. YP often adopt new technology quickly so can act as 'digital champions' for DEOP. Positive benefits of intergenerational activities are also widely reported for YP, many related to educational and developmental gains and improved attitudes towards older people [6]. Work with companion robots demonstrated well how YP's design ideas for technology may be different from older people's expectations [7]. However, intergenerational co-creation may bring ideas that older people had not thought of but are acceptable and useful.

Research codesign is now widely used [8] and there is prior research on intergenerational digital codesign [9]. Our project learned considerably from the prior work on the Generating Older Active Lives Digitally (GOALD) project funded by the Economic and Science Research Council [10]. GOALD tried to take an intergenerational approach to digital design but had problems in recruiting younger people [11]. Nevertheless, we learned from their experience in running codesign workshops and from the guidance for developers of digital products for older people that they produced [12].

The ICONIC project (Intergenerational Co-creation Of Novel technologies to reconnect digitally excluded people In Coastal communities) is a 30-month project. We are taking an intergenerational approach to address digital exclusion in older people and digital economic/employment exclusion of younger people. It is important to know if being intergenerational is a necessary component of co-creation. We need to know if and how this approach leads to differently designed more inclusive technology. We have chosen four technologies that may connect people to community and cultural landscape in our coastal region: extended reality, underwater telepresence, social games and AI voice interfaces.

Immersive experiences can help improve wellbeing for people unable to visit certain places due to mobility problems. This is a major issue for heritage sites, sites of special scientific interest, and coastal landscapes where there is often limited ability to modify construction. Climate change, flood and coastal erosion create additional risks and put increasing pressure on the need to facilitate novel and sustainable visitor experiences, and tourism [13]. *Extended reality* (XR) allows people to experience those spaces virtually and enjoy the wellbeing and psychological benefits. A better understanding of the importance of the marine environment enables us to take this a step further into *underwater telepresence*, celebrating the rich marine environment of D&C.

Connecting with others helps address social isolation and in that respect the importance of technologies, such as videocalls, has been demonstrated in care homes and for people unable to travel during the pandemic. But often more is required than just the opportunity to talk. *Digital social games* have been shown to be a key motivator in connecting, educating, and engaging people and more importantly keeping people engaged. They offer possibilities for the communication of specific values and information while simultaneously engaging previously disconnected audiences. Digital games also have the capacity to engage hard to reach audiences and minority groups but also allow for the valorization of heritage, often a strong motivation for rural regions and marginalized groups. While more generic history-themed digital games are commercially available, the potential health and wellbeing benefits of digital games based on the specific history and historic environment related to the cultural identity of D&C had not yet been explored and so is a focus of ICONIC.

Finally, while the three technologies above can be used to engage individuals with some level of digital awareness, skills and/or device ownership, we need ways to engage those most digitally excluded - those without internet access or digital devices. This group, for reasons of cost, awareness, lack of skills and/or support perhaps due to isolation may never use broadband or own a digital device but nevertheless can be connected to the digital world through existing phone technology. *Voice interaction with the Internet* is now commonplace through smart speakers but making that available by telephone to an older Internet naïve population has had little research. Voice interaction by phone via chatbots to community and cultural resources could help re-connect DEOPs, particularly those with visual impairments.

The ICONIC project therefore aims to co-create appropriate and human-centered technologies focusing on extended reality, underwater telepresence, social games and voice Artificial Intelligence (AI). The project is trying to capitalize on existing cultural and environmental assets in D&C to address challenges faced by both DEOP and YP. ICONIC is necessarily an inter-disciplinary project with a team drawing on computing science (including AI, games, robotics, vision), public health, psychology, architecture, art and design, history and heritage, marine biology, and business studies.

The rest of the paper is structured as follows. In Section II we present ICONIC's research questions and in Section III, the objectives. As this paper focuses on methods, in Section IV, we present our methods in detail. The preliminary results and discussion are in Section V. Section VI concludes our article.

II. RESEARCH QUESTIONS

The six main research questions for this 30-month project are: (i) Is intergenerational co-creation of the four identified technologies feasible? (ii) Does intergenerational co-creation promote an equitable digital society in coastal Britain? (iii) Which of the four technologies are more susceptible to intergenerational co-creation and what preferences do DEOP and YP have in using these technologies? (iv) Which approaches lead to a sense of connection with community and cultural landscape for DEOP and help develop confidence, communication skills, and employability for YP? (v) Does intergenerational co-creation lead to differently designed technology with more potential for inclusivity? (vi) What are the technical and social requirements to develop, adopt, scale-up, spread and sustain these technologies?

III. OBJECTIVES

The objectives of ICONIC include: (i) To engage with local partners who will help with recruitment and who have various digital resources related to the social, environmental, and heritage assets of the region; (ii) To recruit 120 participants (80 DEOP, 40 YP) with the help of those external partners; (iii) To codesign four novel technologies by taking an intergenerational approach in a series of workshops; (iv) To document group working by external observation and internal reflection to assess the impact of intergenerational working between the four technologies on design; (v) To assess whether using the four co-created technologies improves digital access and wellbeing and sense of connection for DEOP or digital involvement or digital employability of YP; (vi) To explore sustainability through opportunities of embedding these processes into curricula for further and higher education students.

IV. METHODS

A. Regional Partner Organisations

An initial stage (Objective (i)) was to meet with existing partners to explain ICONIC's aims and to explore their related resources and needs. By December 2023 we had met with and had the support of 35 organizations (Table 1). Some partners had both resources and experience of using digital to engage with the digitally excluded. For example, the Ocean Conservation Trust runs the 'Oceans For All' sessions, in which residents can view 360 degree videos recorded inside the tanks of the National Marine Aquarium (NMA) in Plymouth, and Geevor Tin Mine in Cornwall have developed a Virtual Reality (VR) tour to provide remote access to their 18th Century mine-workings heritage site. To support voice AI development, we are working with small and medium enterprises (SMEs) including PatientCards, who are providing access to their social prescribing network that can be accessed through the Help@Hand mobile application, which can provide a sample information available through the technology.

B. Recruitment of Participants

We have worked with our partners to recruit older people (aged 50 or over) and younger people (aged 16-30) (Objective (ii)). The project has ethical permission from the University of Plymouth Arts, Humanities and Business Research Ethics and Integrity Committee (09/05/23; project ID 3941). Our primary method of recruitment has involved recruitment partners (Table 1) sharing adverts of the project with potential participants. This strategy was supplemented through contacting additional groups (such as the University of the Third Age, a network that supports education for retirees) that are not partnered with the project directly, to attempt to recruit participants that are 'digitally excluded'. Further recruitment of YP was conducted through the University, to ensure an intergenerational component for the workshops. Although university students are not a good fit for 'digitally excluded' some, such as nursing students are not particularly digitally proficient and given problems of recruiting younger people we have compromised to ensure the intergenerational aspect of the project. Participants are reimbursed for their participation with vouchers, with additional vouchers available to cover costs of transport and time to travel to the workshop venue. Before the first workshop, we meet with participants either in-person or remotely (via phone or Zoom) and they are interviewed to gauge their current engagement with digital technologies, local heritage and the environment, and their local communities. By December 2023 we had recruited 47 DEOP and 22 YP. Outside of networks within the University of Plymouth, recruiting YP has proven more difficult than recruiting DEOP due to workshops conflicting with working or education hours. This is being addressed through embedding workshops within work being conducted by community groups in Cornwall that work with YP.

As participants are being recruited from a diverse range of backgrounds, there is considerable variation in the nature of digital exclusion reported in their recruitment interviews. Participants have reported barriers to accessing technologies, including lack of skills, costs, and poor local infrastructure [14]. One commonality across most participants, however, is a keen interest to learn more about the technologies being codesigned as a part of the ICONIC project. Participants have shown the greatest interest in the Underwater Telepresence technology, with XR a 'close second', as both technologies can be used to make difficult to access spaces more accessible to a wider audience. Social games technology has registered the least interest from participants, with some older participants reporting negative attitudes to digital games.

C. Overview of the codesign workshops

Objective (iii) is to codesign four novel technologies by taking an intergenerational approach in a series of workshops. The iterative process of technology development we are using is like Participatory Inquiry approaches generating knowledge collaboratively and iteratively where research and action are linked through critical reflection [15]. Our approach is based on an extension of the Participatory Inquiry method called Research through Design [16]. Stakeholders are involved at all development stages of the project from initial problem-framing to the later development stages (for example, designing interactions). To accommodate the iterative nature of the codesign process, we have set up monthly time-boxed development windows and each technology will have between 7 to 10 workshops. From the technical point, this setup provides a suitable timeframe to plan, develop the technology, deliver the workshop, and analyze the results of the workshop to generate knowledge (Figure 1). One of the main benefits of the monthly workshops is repeated, consistent interaction with the participants: a key ingredient for building a productive collaborative relationship.

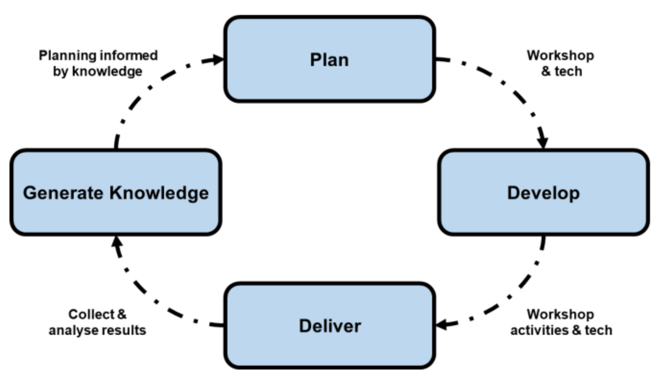

Figure 1. Monthly iterative process used to extract knowledge from the codesign process. The outcome of each process is being used to inform the planning and delivery of the next workshop.

TABLE 1. SUMMARY OF 35 PARTNER ORGANISATIONS SUPPORTING WORK ON THE ICONIC PROJECT SHOWING THEIR ROLE IN EITHER PARTICIPANT RECRUITMENT (PR) OR TECHNOLOGY CONTENT (TC).

Partner	Brief Description of Partner	Role
Abbeyfield	Charity providing housing, residential care and support to older people [17]	PR
Age UK Cornwall	Charity supporting older people (federated independent branches) [18]	PR
Age UK Plymouth	Charity supporting older people (federated independent branches) [19]	PR
Carnon Downs	Village community/hall in Carnon Downs, Cornwall [20]	PR
Centre of Pendeen	Village community/hall in Pendeen, Cornwall [21]	PR
City College Plymouth	Plymouth Further Education college, providing education for students aged 16+ [22]	PR
CN4C	Social enterprise supporting individuals in Cornwall with economic/social issues [23]	PR
Cornish Mines	World Heritage Site preserving 18th and 19th century mining sites in 10 locations [24]	TC
Cornish Mining NT	Heritage Site preserving Tin Coast mining region: 3 locations in west Cornwall [25]	TC
Cornwall AONB	National Park (Area of Outstanding Natural Beauty) covering approximately 27% of Cornwall and comprising twelve separate areas, eleven of which are coastal [26]	TC
Cornwall College	Cornwall Further Education college, providing education for students aged 16+ [27]	PR
Cornwall Digital Exclusion Network	Team embedded in Cornwall Council to support access to digital tools and services in Cornwall and the Isles of Scilly [28]	PR
Cornwall Museums Partnership	Charity that works collaboratively across museums in Cornwall to promote wider engagement with Cornish heritage [29]	TC
Cotehele National Trust	An estate with a medieval house that has been developed across the Tudor and Victorian eras additions located in the east of Cornwall run by National Trust [30]	TC
Dartmoor Nat. Park	Historic national park in south Devon with extensive Bronze Age heritage [31]	TC
Exmoor National Park	National Park located in Somerset and north Devon [32]	TC
Geevor Tin Mine	Historic 18th century mine site in west Cornwall [33]	TC
Healthwatch Torbay	Non-profit organisation supporting health and social care in Torbay, Devon [34]	PR
PatientCards	SME running the Help@Hand social prescribing mobile application used as information sources by the ICONIC Voice AI technology [35]	TC
Hi9	SME specialised in voice AI interfaces [36]	TC
iSight Cornwall	Charity supporting individuals with sight impairments in Cornwall [37]	PR
Made Open	SME that runs Cornwall Link and Devon Connect directory websites used as information sources by the ICONIC Voice AI technology [38]	TC
Minack Theatre	Historic open-air theatre in west Cornwall, with views over Porthcurno Bay [39]	TC
Mount Edgcumbe	Historic Park and stately home in south-east Cornwall [40]	TC
Newquay Orchard	Community group in Newquay, Cornwall [41]	PR
Nudge	Community group in Plymouth [42]	PR
Ocean Conservation Trust	Charity focused on ocean conservation, that runs the National Marine Aquarium, Plymouth [43]	TC
Plymouth CH	Plymouth Community Homes (PCH) -Large housing association [44]	PR
Plymouth Digital Exclusion Network	Team embedded in Plymouth City Council to support access to digital tools and services in Plymouth [45]	PR
Plymouth Sound National Marine Park	The UK's first national marine park, based in Plymouth Sound [46]	TC
Saltram National Trust	Park and Georgian stately home near Plymouth run by National Trust [47]	TC
South Devon AONB	'Area of Outstanding National Beauty' National Park located in south Devon [48]	TC
South Devon College	Further Education college in Torbay, providing education for students aged 16+ [49]	PR
The Eden Project	Attraction in Cornwall comprising domes housing emulations of natural biomes [50]	TC
Torbay Community Development Trust	Charity supporting community development in Torbay, South Devon [51]	PR

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D. Extended Reality (XR)

Our work with XR technologies aims to give older people with mobility impairments access to experiences in sites of cultural and historical significance, addressing the limitations of commercially available VR systems while creating bonds with specific places and communities. This builds upon previous work on the development of XR systems for digital heritage, which focused on Powderham Castle and the Higher Uppacott medieval site in Dartmoor National Park [52]. We are focusing on Cotehele (Table 1), a site managed by the National Trust which preserves a series of medieval buildings and historic garden in Cornwall. Despite the best efforts of its local team to improve accessibility and the visitor experience, the site includes buildings with some accessibility issues, such as narrow corridors and steep steps, and limited public transport.

Between August and December 2023, we ran five workshops with a total of 12 DEOP and 6 YP. We used a Quest 2 headset by Meta to give participants a VR immersive experience (Figure 2). Activities included multiple methods of documenting, experiencing, and speculating about historical sites and their potential to elicit wellbeing principles such as social cohesion and intergenerational interactions. These included 360 video demonstrations, persona-based experience design workshops, and activities to test ergonomics of XR hardware for older users. The latter resulted in the development of bespoke controlling and handling functionalities for the Quest 2 headset. We 3D scanned and documented artefacts for the Cotehele team as part of our partnership working. XR workshop activities will resume in June 2024 to address the integration of locomotion and interaction design elements, and to incorporate narrative and storytelling strategies on the final codesign of XR experiences.

Figure 2. Participant trying out a virtual reality environment via a head mounted display in one of the codesign workshops.

E. Underwater Telepresence

We want to give people the feeling of being underwater while onshore and to see an environment they have never seen before. Our initial codesign workshops revealed several barriers to engaging with the underwater world, such as financial constraints, time commitments, physical fitness requirements, and discomfort due to cold water. While initially, we intended to deliver the experience via a remotely operated vehicle, through a scoping review [53] we identified other potential technological implementations of underwater telepresence characterized by the trade-offs between accessibility, interactivity, as well as the complexity of installation and maintenance. Between September 2023 and February 2024, in partnership with the NMA, we ran five workshops with a total 12 DEOP and 6 YP, where through focus groups, problem-framing, physical prototyping and educational technology demo sessions, a preference emerged towards an immersive, real-time experience of a local underwater environment with on-demand access to information about the surroundings. These preferences have been distilled into a prototype of a live video streaming from a static 360 camera with a backend marine life classification engine and a simple user interface delivered over the head-mounted display with interactive controllers.

F. Digital Social Games

Digital games are a key technology for engaging with user groups that are often hard to reach otherwise. Social games, adds a social component into the mix, which allows the formation or retention of communities. We aim to develop a new digital social game creation framework inspired by casual game creation apps [54] such as Wevva [55] that will provide co-creation groups with the technology for understanding, exploring, and creating games while not having access to more expensive computing hardware. In discussion with project partners NMA "Blue Meadow team" we decided to focus development on the topic of seagrass and its growing process. The beneficial role of seagrass as part of the local ecosystem and its ability to combat the effects of climate change identifies with the ethos and beliefs of the local coastal community. Thus, making it an ideal candidate theme for a social game. The topic also provides links to another technology in the project our work with underwater telepresence and builds on local strengths. The codesign process for social games will take place over seven workshops starting in the first quarter of 2024 covering every stage of development (Figure 1). We start with the problem-framing process and introduction to game design aspects followed by the introduction of social features and culminating in an application that follows the steps of seagrass cultivation. The lessons, tools and approaches used during game development will become the foundation of an open-source framework that will enable the development of similar games for social enterprises.

G. Voice AI (Phone-based Access to Internet Services)

Nearly 40% of those 75+ in the UK had never used the internet in 2020 [56]. Providing them with phone access to the Internet is one way to address such digital inequality. But even among those with internet access, previous research has shown that older people may abandon voice assistant services on smart speakers after unsuccessful attempts [57].

We will work with older and younger participants to discover how older people with no previous computer experience would want to interact with various resources. The main objective is to create bidirectional voice communication with internet services through phone calls, which can be achieved through an IP phone (IP PBX) server that is called by the DEOPs so that it connects them to the application programming interfaces (APIs) of the cloud-based voice assistants (e.g., Amazon Alexa) and services (Caller Smart Speaker API. These intelligent assistants receive voice-based instructions or questions from DEOPs and reply to them through the phone using the available information online or through the other connected service APIs.

This is being explored in the context of ‘social prescribing’ [58], which is an approach to connect people to community activities, groups, and services for their health and wellbeing in primary care. We have discussed with our content-provider partners trialing voice access to: (i) Cornwall Museum audio archives, (ii) the Help@Hand app by Patientcards for community group information, and (iii) Cornwall Link by AgeUk Cornwall, a website by Made Open. Our initial focus is the Help@Hand application, which has diverse activities, events, and services. We are conducting six codesign workshops starting January 2024, involving older and younger participants to design user-friendly voice interfaces. These workshops will employ common conversational interaction design tools like Wizard-Of-Oz (WoZ) for prototyping [59] Our pilot workshop revealed a need to explore subtle voice interaction features like pauses and intonations for natural voice interaction. We have partnered with Exeter University's conversational analysis group to study these features to enhance user satisfaction and engagement in the provided service.

H. Exit Interview, Evaluation and Analysis

Participants will be interviewed on leaving the study to gauge their assessment of the intergenerational interactions within the workshops. We will also use workshop recordings to identify patterns in how the generations work together or if there are specific technical preferences associated with either age group. Some preliminary observations from workshops for the first two technologies suggest that DEOP tend to take the role of ‘directors’ and let the YP do the hands-on design activities/idea presentation. We will adapt and adjust our methods to try to get the best from this aspect of the study design. The participant ‘exit interview’ will be used to assess whether using the four co-created technologies improved their digital access, wellbeing and sense of community and environmental connection (for DEOP), or digital involvement and digital employability (for YP) (Objective (v)). Finally, we will be discussing with the further and higher education providers among our partners how to sustain opportunities and embed these processes into curricula for their students (Objective (vi)).

V. PRELIMINARY RESULTS AND DISCUSSION

We are making progress in our aim to develop four novel technologies codesigned by intergenerational groups of people who are in some way digitally excluded living in coastal communities.

We managed to engage 35 partner organizations and by December 2023 had recruited 69 of our target 120 participants for workshops. Recruitment is difficult due to the requirement of older participants to be digitally excluded, and the availability of YP, meaning we have not yet reached the same intergenerational participant balance as other projects [60]. Attracting DEOP has required a focused effort to work with the project’s partners to share the project’s messaging. This has proven a successful approach, as it has allowed us to set up workshops in digitally marginalized areas, in which participants have articulated clear issues with the local digital infrastructure. A further barrier has been a lack of interest in the project from some groups due to the desire for more foundational access to technology, that can offer practical support for using digital technologies. It is difficult to recruit YP for synchronous events as they may be working or studying during daytime when DEOP want to meet, but our work to date has shown the importance of intergenerational collaboration [61]. Our approach in offering participants direct reimbursement appears to be more successful than methods used in GOALD [10][11]. We are pursuing various approaches to solve these problems including embedding the workshops in local community groups that work with YP and exploring the use of more distributed/asynchronous codesign methods that have been employed in response to the COVID-19 pandemic [62].

A further lesson from the codesign sessions is the importance, when working with digitally excluded older adults, to articulate the researchers’ impartiality, and emphasize the need to learn about the difficulties. Part of this messaging involves articulating that the project is not designed to push technology, but to identify how technology can support societal inclusion and support vulnerable populations, but also identify current barriers to vulnerable populations that prevent their access to digital resources.

Finding a niche for new technology development is also difficult given the rapidity of background technology developments. This is an unusual project in that we work very hard to engage the digitally excluded and with them to identify novel technologies while novel technologies are most frequently designed by those deeply embedded in and at the cutting edge of technology development. We are trying to be in ‘two places at once’ – looking at the digital accessibility needs of those who are infrequent users of technology, trying to make sure that their voice is heard by the technology developers.

Our project’s impact may be limited by the short timescale of digital developments. We may also be limited by the findings from this one geographical locality. It may therefore be difficult to find generalizable design recommendations, but we hope that at least the observations on our methods will be generalizable to other locations. It is quite a difficult ‘space’ to occupy but we think it is worth it.

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Advancing Sustainability in Global Supply Chains through Agent-based Simulation

Haoyu Wang
NEC Labs America
Princeton, USA
haoyu@nec-labs.com

Erhu He, Can Zheng
University of Pittsburgh
Pittsburgh, USA
{erh108,caz51}@pitt.edu

Lu-An Tang, Zhengzhang Chen, Xujiang Zhao
NEC Labs America
Princeton, USA
{ltang,zchen,xuzhao}@nec-labs.com

Xiaowei Jia
University of Pittsburgh
Pittsburgh, USA
xiaowei@pitt.edu

Haifeng Chen
NEC Labs America
Princeton, USA
haifeng@nec-labs.com

***Abstract*—In today's world, with its complex global supply chains, the difficulties and uncertainties we face offer both challenges and opportunities for making things better, especially in terms of efficiency and sustainability. These challenges grow due to unpredictable events, such as natural disasters, unexpected incidents, and unusual business practices, pushing us towards more advanced modeling methods that focus on reducing risks and enhancing sustainability. In this paper, we present a new agent-based simulation approach that goes beyond the usual limits of supply chain simulations by incorporating sustainability directly into supply chain operations using Reinforcement Learning (RL) algorithms. We introduce MOGI, derived from the Japanese word for 'simulation', a sustainable supply chain simulation system that takes carbon emissions into account in its main operations. Additionally, we examine how effective a multi-agent RL strategy is in dealing with the complex and uncertain nature of supply chains that span multiple levels. By comparing this strategy with traditional heuristic methods, our study looks at how well single versus multiple RL agents can manage risks and improve sustainability in both the beginning and end parts of the supply chain. The results of our experiments show that strategies based on RL are much better than traditional methods at managing risks, making profits, and achieving sustainability goals.**

***Index Terms*—Agent-based Simulation, Supply Chain, System Optimization**

I. Introduction

In the evolving landscape of global Supply Chain Management (SCM), mitigating carbon emissions has emerged as a critical concern. This imperative addresses not only environmental sustainability but also operational efficiency and regulatory compliance. The complexity of modern supply chains, characterized by intricate networks of suppliers, manufacturers, and retailers across diverse regions, poses significant challenges in accurately quantifying and managing carbon footprints. With ambitions toward achieving a net-zero economy, numerous countries are adopting varied sustainability policies [2], [3]. To meet internationally agreed-upon climate goals, optimizing supply chain management by integrating carbon emissions considerations is essential.

Efforts to reduce carbon footprints in supply chain management necessitate a comprehensive approach that incorporates robust strategies to address traditional uncertainties while actively striving for sustainability and carbon neutrality. This approach ensures that supply chains not only achieve their economic objectives but also contribute positively to environmental stewardship. Machine Learning (ML) has become increasingly prevalent in enhancing SCM, particularly in improving demand forecasting and sales predictions [7], [12], [14], estimating commercial partnerships [10], [11], and optimizing inventory management [9], [15]. However, reliance solely on ML techniques presents certain limitations, including the lack of transparency in the decision-making process and the intensive requirements for training data and computational resources. These challenges necessitate either advanced domain expertise for developing sophisticated and experiential strategies or substantial datasets for model training, which can be particularly challenging to acquire, especially in the context of proprietary commercial data.

Considering the identified limitations of ML methods in addressing supply chain challenges, an increasing number of researchers are integrating simulation-based methods with ML to tackle these issues [1], [5]. To this end, we introduce MOGI, a simulation tool tailored for general complex problems. MOGI encompasses three critical components: a comprehensive agent-based simulation engine, a resource management system, and an interactive platform for the implementation and testing of policies. Designed for efficiency and scalability, MOGI is adept at simulating complex scenarios involving numerous agents and complex resource flows. Owing to its capability to monitor every detail of each component within the simulation framework, MOGI facilitates the calculation of product-level carbon emissions with a precision that surpasses previous methods.

Reinforcement Learning (RL) has emerged as a critical technique for optimizing agent-based simulations in supply chain management, attributed to its unparalleled capability to navigate complex, uncertain environments. Firstly, supply

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chain management necessitates sequential decision-making amidst uncertainty, a domain where RL excels by optimizing decisions across time to favor long-term rewards over immediate gains. This approach is vital for supply chain decisions, considering that short-term actions may lead to enduring consequences. Secondly, RL can model and learn complex behaviors directly from agent-interaction data, obviating the need to explicitly enumerate all conceivable states and actions—a task impractical for complex systems. In this study, we apply RL to each simulation agent and assess various RL algorithms to facilitate optimization of supply chain management towards achieving carbon neutrality.

The contributions of this paper are summarized as follows:

- We have developed an agent-based supply chain simulator, MOGI, capable of simulating detailed interactions among supply chain components, with an emphasis on sustainability attributes.
- We investigate the potential and limitations of multi-agent reinforcement learning algorithms in reducing supply chain uncertainty by extending the supply chain to include participants across various tiers.

This paper is organized as follow. Section II introduces the previous work about supply chain system simulation and reinforcement learning. In Section III, we defined the supply chain system optimization problem. In Section IV, we introduce MOGI simulator in detail including all the key components. In Section V and Section VI, we introduce the reinforcement learning used in MOGI simulation evaluation and the experiments respectively. In Section VII and Section VIII, we conclude this paper and introduce the future work.

II. Related work

Agent-based simulation tools are increasingly employed in supply chain management to facilitate the exploration of complex interactions among individual agents, which may represent companies, consumers, or products, within the supply chain network. Tools such as AnyLogic [1], Simio [5], and MATSim [4] exemplify agent-based supply chain simulation platforms. Nevertheless, these tools do not explicitly focus on sustainability within the supply chain, nor do they extend to the precise calculation of product-level carbon emissions.

Since there was a lack of relevant research on supply chain management in sustainability, based on our exploration, the closest previous work is the application of RL in inventory management. In this type of problem, the RL-agent first observes the current state of the system, including current inventory levels, demand patterns, lead times, etc. The RL-agent is then required to determine order quantities or reorder points, and the environment responds by generating new states and providing rewards or penalties to guide the learning process. As a typical case of downstream uncertainty, the variant demands are considered as the drive for reinforcement learning solution in many researches, and the adaptive balance between customer satisfaction and storage cost need to be found. Zwaida [6] propose an online solution with deep Q-network (DQN) algorithm to prevent drug shortage problem in hospital by deciding the refilling time and the amount of ordered drugs, balancing the shortage cost and overstock cost. Ganesan et al. [8] train the RL-agent to select the optimal strategy from five pre-defined policies by considering the combination of shortages, frequency of shortages and surplus inventories over the past n periods. Sedamaki et al. [13] classify suppliers to four risk indices and train the RL-agent in a custom-modeled environment to slit an order among multiple suppliers while minimizing the delays.

III. Problem Definition

The goal of our work is to develop a simulation tool to model supply chain system behaviors with a focus on sustainability, aiming to optimize supply chain decision-making for lower carbon emissions and reduced uncertainty. To assess the MOGI simulation tool and the RL optimization methods for system sustainability, we transform a real-world supply chain system focusing on sustainability into an optimization problem aimed at lowering carbon emissions. Consider a supply chain system with I retailers (agents in the simulation) interconnected in a specific topology. At time point t within period T, the i^{th} retailer purchases $m_{ij}(t)$ units of the product from the j^{th} supplier at price $n_{ij}(t)$. Subsequently, the i^{th} retailer sells $m_{ik}(t)$ units of the product to the k^{th} customer at price $n_{ik}(t)$. Given that carbon emissions are predominantly calculated during the manufacturing process, the carbon emissions associated with the transaction between the i^{th} retailer and the j^{th} supplier are represented as $m_{ij} * E_{ij}$, where E_{ij} is the product-specific carbon emission factor. Thus, the objective is to maximize the profit earned by all retailers while accounting for the equivalent carbon emissions, as illustrated below:

$$max \sum^{T} (\sum^{I} m_{ij}(t) * n_{ij}(t) - \sum^{K} E_{ik} * m_{ij}(t)). \quad (1)$$

For clarification, we use the term "agent" in this article to refer to the agent both in simulation system and real-world environment and "RL-agent" to refer to the agent in RL only.

IV. MOGI: Supply Chain Simulation

In this section, we introduce MOGI, an agent-based simulation tool designed for general complex system modeling. This paper demonstrates the application of MOGI in supply chain management with a focus on sustainability. We use the supply chain system as a case study to elucidate MOGI's rationale and the methodology for mapping real-world systems into the simulation environment.

A. Overview of MOGI Simulation

A general complex system is comprised of interacting, autonomous components. Unlike simple systems, complex adaptive systems possess the ability for agents to adapt at the individual or population levels. This exploration into complex systems forms the basis for understanding self-organization, emergent phenomena, and the origins of adaptation in nature. Conceptually, the decomposition of a general complex

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system into three primary components—Agents, Resources, and Topology—is derived from a holistic approach to modeling and comprehending the intricate interactions and dynamics within such systems. Agents within the system have the capacity to act, interact, and make decisions based on predefined rules or through adaptive learning mechanisms. Resources include the various elements and assets that can be consumed, transformed, or produced by agents within the system. Topology refers to the arrangement and connectivity of elements within the system, highlighting the structural aspect of complex systems. It delineates how agents are linked and the manner in which they can interact with one another. This framework not only facilitates the conceptual understanding of complex systems but also enables structured simulations to explore system dynamics, predict behavior under diverse scenarios, and devise interventions to achieve specific objectives. The diagram shown in Fig. 1 exemplifies MOGI's functionality, orchestrating resource flow dynamically through the supply chain. The module is pivotal, facilitating the simulation of diverse supply chain strategies and their impacts on efficiency and sustainability.

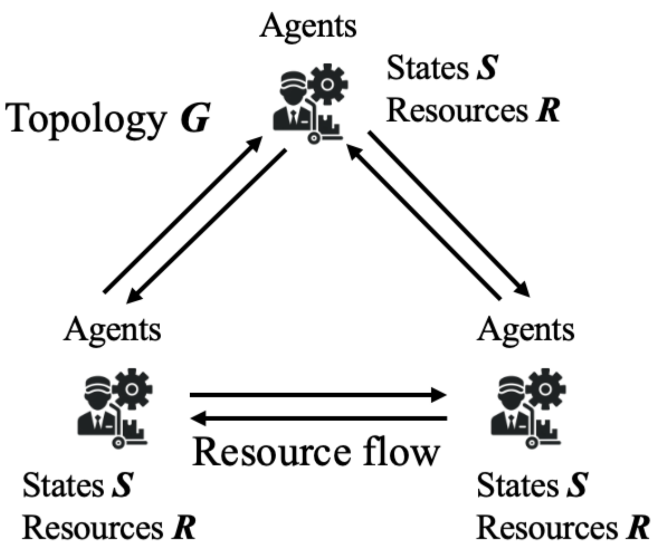

Fig. 1. MOGI in supply chain simulation.

B. Agent

Agents are entities within the system capable of acting, interacting, and making decisions based on predefined rules or adaptive learning mechanisms. Each agent is endowed with the ability to process information, utilize resources, and potentially alter the topology through their actions. The complexity of real-world systems emerges from the collective behaviors of agents, leading to phenomena such as self-organization, adaptation, and evolution.

The design and description of agents within a simulation are predicated on several essential characteristics. First, an agent is a self-contained and uniquely identifiable entity with attributes that enable it to be distinguished from and recognized by other agents, facilitating interaction. Second, an agent is autonomous and self-directed, capable of operating independently within its environment and in interactions with other agents. An agent's behavior, which bridges sensed information to decisions and actions, can range from simple rules to complex models, including RL mechanisms that adapt inputs to outputs. Third, an agent possesses a state that evolves over time or in response to external changes. In MOGI, we employ a state machine mechanism within each agent to represent its state. This mechanism is chosen for its inherent ability to model the discrete states and transitions that define the operational and decision-making processes of agents. In the context of supply chain systems, this approach is particularly apt, as it mirrors the operational stages and decision-making sequences in procurement and manufacturing processes, among others.

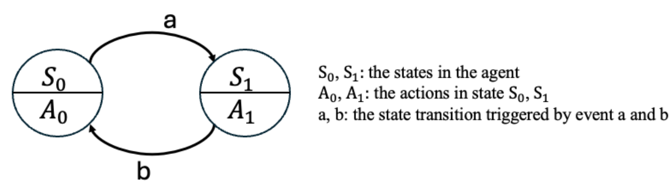

Fig. 2. State machine in MOGI agent.

A general example of a state machine within an agent is depicted in Fig. 2. This figure shows a state machine comprising two states: State 1 and State 2. Each state triggers a specific action, denoted as Action 1 and Action 2, respectively. The diagram also illustrates a uni-directional transition from State 1 to State 2, initiated by a designated event. This transition symbolizes a shift in behavior, as indicated by the distinct actions associated with each state.

Within MOGI, agents function according to a behavioral model that promotes autonomy and responsiveness to other agents. This model incorporates decision-making algorithms that enable agents to adapt to the evolving conditions of the simulation environment, thus mirroring the uncertainties and dynamics typical of real-world supply chain operations. Agents evaluate their performance metrics, such as delivery times and production rates, and adjust their strategies accordingly to optimize these variables. The model guarantees that agents' actions are responsive to changes in resource availability and demand, creating a self-regulating system that adapts based on simulation inputs and inter-agent interactions.

C. Resource

The resource component manages the both tangible and intangible resources within the connections among all the agents or produced by agents, employing algorithms that adapt to simulation conditions. Resources are allocated based on supply and demand, with the simulation tracking their utilization and wastage. It also simulates the exchange of resources among agents, incorporating factors like market trends and demand forecasts. It ensures a balance between resource consumption and replenishment, aligning with the sustainability metrics modeled within the simulation. Resource dynamics, such as scarcity, competition, and allocation, play a critical role in the agent's behavior and interactions and consequently, in the emergent properties of the system.

The nature and dynamics of resource can greatly impact agent behavior especially under different interaction such as cooperation and competition. For the **cooperation**, the agents work together to share, allocate, or optimize resource in the same direction such as shared benefit or similar goal. Resource in such settings should be designed to encourage collaborative strategies, such as pooling resource to complete a task that no single agent could accomplish alone. Meanwhile, the simulation can explore how cooperation leads to efficient resource use and mechanisms for fair distribution and sustainability. For **competition**, the competitive resource settings can simulate the real-world phenomena such market dynamics, ecological survival strategies, or social competition. The focus can be on how agents adapt the strategies in response to resource scarcity, the impact of competition on resource distribution.

D. Topology

The topology component in MOGI simulates the dynamic connections and interactions between agents and resources. It concerns the arrangement and connectivity of elements within the system, highlighting the structural dimension of complex systems. Topology determines how agents are interconnected, thereby influencing their potential interactions. The configuration of a system's topology plays a crucial role in its dynamics by dictating the channels for information or resource flow and impacting overall system performance. As interactions between agents and resources unfold, the topological structure adapts, shedding light on optimal system configurations.

Topology within simulations can be categorized into **static/dynamic** and **physical/virtual**, accommodating various real-world system types. **Static topology** features a spatial structure that remains constant throughout the simulation period, streamlining the analysis of agent interactions and the influence of spatial arrangements on system dynamics. It suits the study of systems with stable spatial relationships over time, such as those in organization-based simulations, allowing a concentrated examination of other dynamics.

Conversely, **dynamic topology** supports modifications to spatial structures during the simulation, including changes in agent positions, modifications in agent connections, or variations in spatial configurations. This type of topology is crucial for simulating systems where adaptability, movement, or structural changes are integral to behavior, exemplified by social network evolution simulations.

Physical topology deals with the spatial arrangement of agents and resources, taking into account distances, barriers, or spatial distributions that influence interaction probabilities and dynamics. It is applied to simulate real-world spatial dynamics, such as urban traffic patterns. **Virtual topology**, on the other hand, defines connections among agents based on relationships, communication paths, or other non-physical links. It is vital for studying systems where physical locations are secondary to the connections between entities, as seen in simulations of idea development or virtual networks.

V. OPTIMIZATION METHOD

A. Scenario Setup

In this study, our objective is to investigate the impact of supply chain depth on uncertainty management, focusing on a scenario that incorporates multiple suppliers and customers. At the heart of this scenario is an intermediary entity, such as a retailer, which is represented by a decision-making agent (as depicted in Fig. 3). This agent aims to maximize profits through strategic purchasing and selling activities, with a keen consideration for sustainability, herein represented by carbon emissions.

The initial simulated scenario involves three suppliers connected to a central agent, which in turn is connected to three customers (as illustrated in Fig. 3a). These connections symbolize contracts established for the trading of products. To inject an element of uncertainty into the simulation, the connection between a given supplier i and the central agent j may become disabled with a certain probability p_{ij} at any given time step t. Customer demand directed towards agent j is modeled as a random variable that follows a Poisson distribution, represented by d_j. This setup allows the agent to purchase products from suppliers at a quoted price and then sell them to distributors at a price determined by the agent, effectively simulating the dynamic and uncertain nature of customer demand.

To further examine the influence of having multiple multi-level agents in the supply chain on sustainability, the scenario is expanded as shown in Fig. 3 (b). In this more complex setup, multiple agents share the uncertainties, each facing a disruption probability p_{ii} when interacting with another agent. The demand requested by a downstream agent is denoted as d_{ik}, illustrating the extended network and layered interactions designed to explore deeper aspects of supply chain sustainability and uncertainty management.

B. RL method

Because of the traditional optimization methods that struggle to cope with the stochastic nature and the high dimensionality of decision spaces, we apply RL-agent on the agent to make decisions due to its capability to learn optimal strategies through interaction with a real-world system. Meanwhile, the adoption of RL can learn from simulation without real-world risks, deal with uncertainty and partial observability,and facilitate continuous improvement. Next, we introduce the detail of RL (DQN) (as shown in Fig. 4) applied in MOGI.

The learning process of RL-agent can be described by a tuple $(s, a, s', r,)$, where s denotes the current state, a denotes the action will take, s' and r is the new state and reward returned from the environment, respectively, once a is acted 4. We also denote S and A as the set of possible states and actions respectively. The Q-learning algorithm aims to estimate the action by mapping state and corresponding action, $Q : S \times A \to \mathbb{R}$, to a real number so called Q-values. The agent

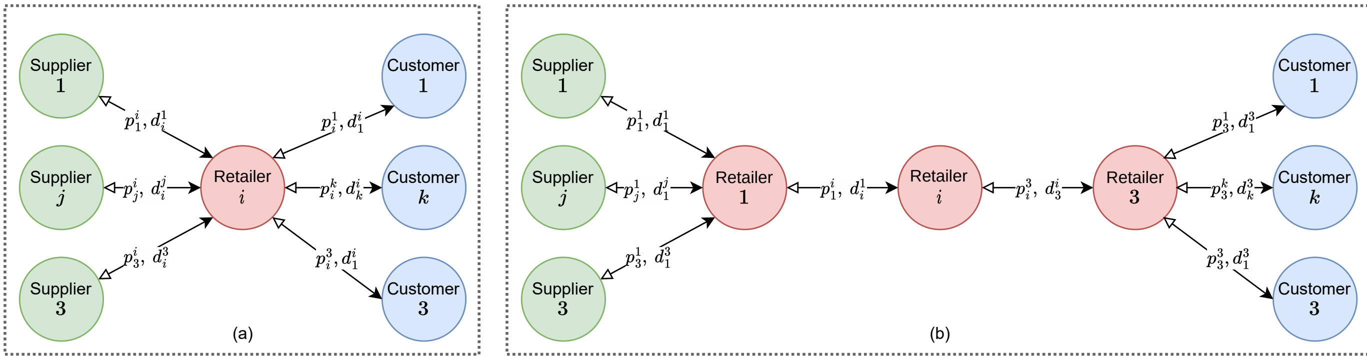

Fig. 3. (a) The basic topology of the supply chain with a single agent balancing with uncertainty from both upstream and downstream entities. (b) A multi-layer agents involved supply chain for uncertainty sharing.

can execute the action with highest Q-values based on the optimal Q-values function, Q^*, to achieve highest accumulated rewards. The optimal Q-values function can be optimized by minimizing the temporal difference error,

$$\delta = r + \gamma \max_{a'} Q(s', a') - Q(s, a) \tag{2}$$

where γ is the discount factor determining the importance of future rewards. Therefore, the we can update the Q-function by,

$$Q(s, a) \leftarrow Q(s, a) + \alpha\delta \tag{3}$$

In the setting of DQN, the Q-value function a learnable deep neural network parameterized by θ instead of the tabular encoding used in standard Q-learning. We can optimize it by

$$L(\theta) = \mathbb{E}\left[\left(Q(s, a; \theta) - (r + \gamma \max_{a'} Q(s', a'; \theta^-))\right)^2\right] \tag{4}$$

where (s, a, r, s') is sampled from the memory buffer D, and θ^- denotes to the parameters of target network.

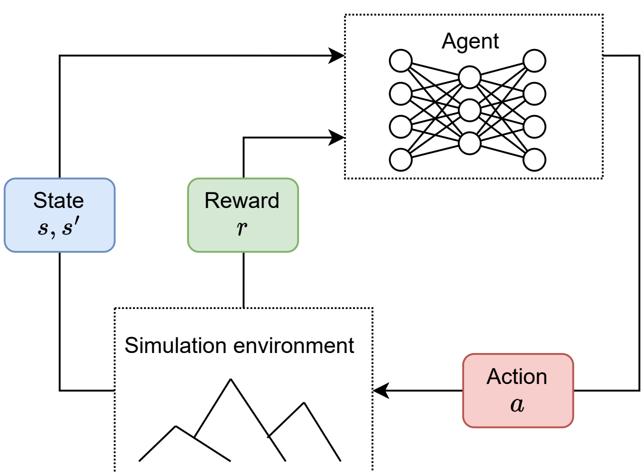

Fig. 4. The comparison of storage level and the number of purchased products.

C. RL Settings

1) State: The state s is defined as a vector embedding the information that can be gained by the agent from the environment. We denote the state of agent i as $s_i = [c_i, \mu_i, x_i, y_i] \in \mathbb{R}_+^{|\mathcal{S}_i|+|\mathcal{R}_i|+l_i+1}$. $c_i \in \mathbb{R}_+^{|\mathcal{S}_i|}$ is the product price from i's supplier; $\mu_i \in \mathbb{R}_+^{|\mathcal{R}_i|}$ is the anticipated demand from i's retailer; x_i is the current inventory level; and $y_i \in \mathbb{R}_+^{l_i}$ represents the product transition line, and $[y_i(t)]_n$ is the replenishment that arrives at time $t + n$.

2) Action: In each time point t, an agent can decide the quantity of purchasing, m_ij, and the selling price n_ik, forming the action vector $a_i = [m_ij, n_ik] \in \mathbb{R}_+^{2N}$. So, m_{ij} is the products amount ordered by agent i from its supplier j.

3) Rewards: We define the rewards in terms of total revenue, order cost, holding cost, backlog cost and equivalent carbon emissions,

$$\begin{aligned} r_i(t) = & \underbrace{\sum_j n_{ij}(t) d_{ij}(t)}_{\text{total revenue}} - \underbrace{\sum_k c_{ik}(t) d_{ki}(t)}_{\text{order cost}} - \\ & \underbrace{h_i \left(x_i(t) \sum_j d_{ij}(t) \right)_+}_{\text{holding cost}} - \underbrace{w_i \left(\sum_j d_{ij}(t) - x_i(t) \right)_+}_{\text{backlog cost}} - \\ & \underbrace{- \sum_k E_{ik} d_{ki}(t)}_{\text{carbon emission}} \end{aligned} \tag{5}$$

Where E_{ik} is the carbon emission for the product. The agent earn the profit by selling products that purchased from suppliers (order cost) to retailers (total revenue) and it aims to reduce the total equivalent carbon emission in the whole process.

VI. EXPERIMENTS

A. Implementation Details

In the experiment, as shown in Fig. 3, the supply chain system includes three suppliers and three customers. An agent can purchase products from the suppliers at quoted prices

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and sell them to distributors at self-determined prices. This model effectively simulates the dynamic and uncertain nature of customer demands. We implement RL (DQN) in the supply chain with one single RL-agent or three RL-agents in Fig. 3 (a) and (b), respectively. In the RL method, the states include the product price from each supplier, the selling price to each customer, and the current inventory amount in each agent. The actions include setting the buying and selling prices of the product and the amount of product purchased by the agent for the next time period. The reward is calculated as shown in Equation 5. Furthermore, we considered the instability of suppliers and transitions, aiming to mimic scenarios where abnormal events occur, which ultimately affect the transaction amount. Therefore, we add a random discount factor to d_{ij},

$$d'_{ij} = d_{ij} \cdot p_{ij}$$

where p_{ij} is a random variable evenly ranging from 0 to 1. We assume customer demand is price-sensitive, such that $Q(n_k) = 10 - 2n_k + 0.05\epsilon$, where $\epsilon \sim \mathcal{N}(0, 1)$ represents Gaussian noise. The RL (DQN) configuration includes two layers with 128 units each for both the value and the advantage streams. We use the Adam optimizer and set the learning rate to 0.001. The discount factor, gamma, was set to 0.99. An epsilon-greedy strategy was employed for action selection, with an initial epsilon of 1.0, which decayed exponentially to a final epsilon of 0.01 over 50,000 steps. Experience Replay was employed to stabilize the learning process. The buffer size for the experience replay was set to 10,000. A batch size of 32 was used to sample experiences from the replay buffer for updating the Q-network. The target network was updated with the weights of the policy network after each episode.

To compare with the RL method, we designed a naive threshold-based heuristic strategy that determines the decision according to a certain threshold. We maintain a safety storage range, composed of sto^+ and sto^- (5000 and 1000 in the experiment, respectively). If the current storage level is lower than sto^-, the agent will purchase the differential product from suppliers, with the order amount being the same. If the current storage level exceeds the range, the agent will stop purchasing and attempt to satisfy all the customers. In other cases, the agent will evenly purchase products from suppliers and distribute them evenly among customers.

B. Result

A single agent implemented with DQN is able to handle uncertainties. Fig. 5 shows the learned purchasing strategy of the agent in the basic supply chain shown in Fig. 3 (a). We can see that the agent purchases products quickly at the beginning and fills the store to a comfortable level around 100 to avoid future shortages. After that, it focuses on selling products and does not make purchases for a long period. When the storage level reaches a median value (~ 50), the agent frequently trades products with suppliers to dynamically satisfy customer demands. The sawtooth fluctuations are caused by the connection disruption. In Fig. 6, we present a comparison of the number of products sold and the total demands from

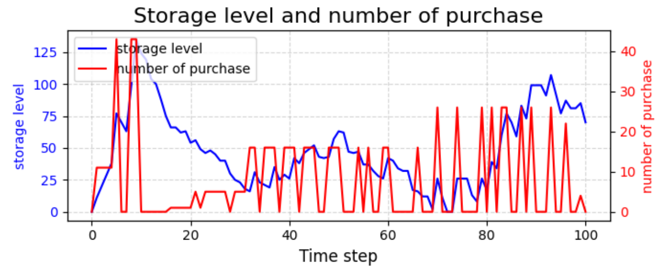

Fig. 5. The comparison of storage level and the number of purchased products.

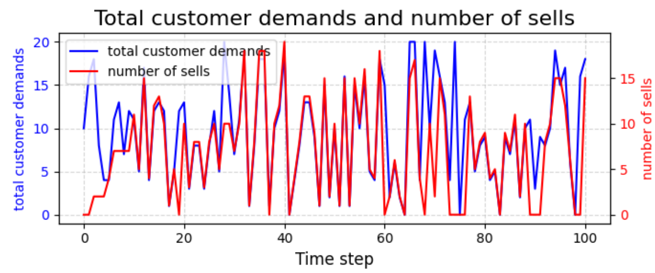

Fig. 6. The comparison of total customer demands and the number of sold products.

downstream customers. It indicates that the learned agent can satisfy customers well in such an uncertain environment. Most of the time, the storage level is equal to or greater than the demands, ensuring that sufficient products can be sold.

Comparison between an RL-agent and an agent driven by a heuristic strategy, we conclude the average profits in 200 simulations (Table I). For single-agent method, the heuristic strategy yielded an average profit of \$183.05 with a standard deviation of \$12.86, indicating a relatively stable performance. In contrast, the single agent employing RL outperformed the heuristic approach with a significantly higher average profit of \$267.87, albeit with a larger standard deviation of \$63.32, suggesting higher variability in the outcomes.

The multi-agent method followed a similar pattern, with the heuristic strategy achieving an average profit of \$215.43 and a standard deviation of \$23.68. The multi-agent strategy utilizing RL demonstrated superior performance with the highest average profit of \$307.19 among all strategies tested, but also exhibited the highest standard deviation of \$79.31, indicating the greatest variability in profit outcomes.

These results underscore the enhanced performance potential of RL strategies over heuristic in both single and multiple agent settings, as evidenced by the higher average profits. However, the increased standard deviations associated with RL strategies also highlight the greater risk in profits, which may be attributed to the dynamic and possibly complex decision-making processes intrinsic to RL algorithms.

VII. Future Work

This research lays a foundational framework for integrating sustainability considerations with reinforcement learning to

TABLE I
AVERAGE PROFITS OBTAINED BY AGENT WITH DIFFERENT STRATEGIES.

MethodS	Average profits (USD)
single agent (heuristic)	**\$183.05**±12.86
single agent (RL)	**\$267.87**±63.32
multiple agents (heuristic)	**\$215.43**±23.68
multiple agents (RL)	**\$307.19**±79.31

enhance supply chain resilience and sustainability. However, the dynamic and multifaceted nature of global supply chains presents numerous avenues for further investigation. Future work will focus on several key areas to extend the contributions of this study:

Enhanced Model Complexity: Expanding the complexity of the MOGI simulation system to incorporate more granular sustainability metrics, such as water usage, land use, and biodiversity impact. This would allow for a more comprehensive assessment of environmental stewardship across the supply chain.

Advanced Reinforcement Learning Algorithms: Investigating the application of more advanced reinforcement learning algorithms, including deep reinforcement learning and multi-agent reinforcement learning strategies, to better capture the complexities and dynamics of global supply chains.

Supply Chain Collaboration Mechanisms: Developing mechanisms for enhanced collaboration and information sharing among supply chain participants. This includes exploring the role of blockchain and other decentralized technologies in fostering transparency and trust in sustainable supply chain practices.

Policy and Regulatory Impact Analysis: Analyzing the impact of policies and regulations on supply chain sustainability and resilience. Future research could model the effects of different regulatory frameworks on supply chain decisions and outcomes, providing insights for policymakers.

LLM-Enabled Agent-Based Simulation: Building upon the integration of advanced AI techniques, future research will explore the application of Large Language Models (LLMs) within the agent-based simulation framework to facilitate more sophisticated communication and decision-making processes among agents. LLMs can be utilized to enable agents to process and interpret natural language data, allowing them to extract actionable insights from unstructured data sources such as news articles, social media feeds, and industry reports. This capability will significantly enhance the agents' ability to anticipate and react to real-world supply chain disruptions and trends by understanding the context and sentiments expressed in global news and market analyses.

VIII. CONCLUSION

This paper studied the complexities and challenges inherent in today's global supply chains, underscoring the need for innovative approaches to manage uncertainties and enhance sustainability. By introducing the MOGI sustainable supply chain simulation system and employing a multi-agent reinforcement learning strategy, we have a significant step forward in addressing these challenges. Our findings reveal that reinforcement learning, when applied across a multi-level supply chain topology, not only improves risk management and profit margins but also significantly advances environmental, social, and economic sustainability objectives. The comparative analysis with heuristic strategies further emphasizes the superiority of reinforcement learning in navigating the uncertainties that plague global supply chains. This research contributes to the broader discourse on sustainable supply chain management, showcasing the potential of advanced simulation techniques to fortify supply chain resilience and sustainability amidst a volatile global landscape.

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Creating Renewable Energy and Energy Efficiency Awareness

A Case Study on a Public Energy Awareness Campaign

Lasse Berntzen
School of Business
University of South-Eastern Norway
Horten, Norway
e-mail: lasse.berntzen@usn.no

Claudiu Isarie
Faculty of Engineering
Lucian Blaga University of Sibiu
Sibiu, Romania
e-mail: claudiu.isarie@ulbsibiu.ro

Marius Rohde Johannessen
School of Business
University of South-Eastern Norway
Horten, Norway
e-mail: marius.johannessen@usn.no

Mihaela Rotaru
Faculty of Engineering
Lucian Blaga University of Sibiu
Sibiu, Romania
e-mail: mihaela.rotaru@ulbsibiu.ro

***Abstract*— This paper presents the outcomes of the collaborative project "Renewable Energy and Energy Efficiency for Sustainable Development in Sibiu County," conducted jointly by Sibiu County, Romania, Lucian Blaga University of Sibiu (LBUS), Romania, and the University of South-Eastern Norway (USN). The paper presents an awareness campaign targeting citizens and schools to foster understanding and adoption of renewable energy and energy efficiency practices. Emphasizing the importance of smart energy solutions, the paper introduces the Technology Acceptance Model (TAM) as a framework for understanding user acceptance of new technologies. The awareness campaign utilized offline and online channels, with an estimated reach of 150.000 citizens, while engaging educational institutions to cultivate sustainability awareness from an early age. The paper also discusses the development of an environmental protection course for university students. A SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis highlights the campaign's strengths, weaknesses, opportunities, and threats. The paper also discusses challenges met when running energy awareness campaigns. The paper underscores the significance of behavior change in achieving sustainable energy goals.**

Keywords: renewable energy; energy efficiency; awareness; campaigns; social media.

I. INTRODUCTION

The collaborative project "Renewable Energy and Energy Efficiency for Sustainable Development in Sibiu County," a joint effort between Sibiu County, Romania, Lucian Blaga University of Sibiu (LBUS), Romania, and the University of South-Eastern Norway (USN), aimed to increase public awareness of renewable energy and energy efficiency [1].

A previous paper [2] focused on a training program targeting Small and Medium-sized Enterprises (SMEs) and public institutions. The paper discussed the strengths and weaknesses of the current Sibiu County strategy identified during training sessions with technical specialists.

This paper reports on a broader awareness campaign targeting the citizens and schools. In recent years, citizens have become extensively aware of the environment, demonstrating their openness to changing their behavior, particularly related to renewable energy and energy efficiency. Public awareness and government incentives have accelerated the interest in sustainable energy solutions.

The focus of this paper is not government incentives but how a regional government can help inform and educate citizens to help them understand the potential of renewable energy and energy efficiency.

Smart energy is not only about installing solar panels or better building insulation. It is about using smart devices to automate or guide users to reduce their energy consumption. It is possible to reduce the load on the electricity grid in specific periods of the day and shift energy consumption to other periods of the day. This is called "peak shaving" and "load shifting" [3].

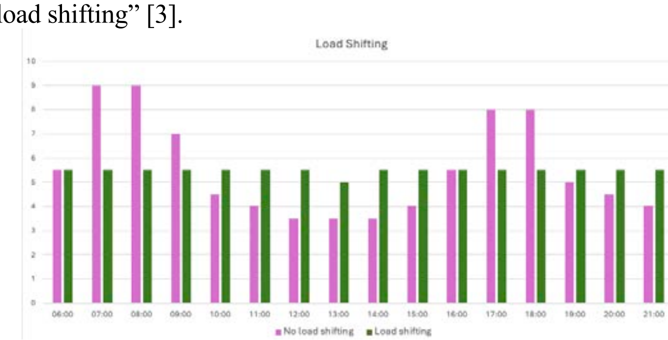

Figure 1. Load shifting in practice.

One example is charging an electric vehicle when the grid demand is low. When the market is low, the price is

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more beneficial. Electric water heaters can be turned on during the day when solar panels provide energy. Since the water heater works as a thermos, it will keep the water warm for later consumption. Fig. 1 shows how load shifting can reduce peaks by moving consumption from peak to non-peak periods. This can be done for a single household, a local grid, or a larger scale.

Smart digital solutions to control household energy consumption are available in the market. However, more than the availability of technology itself is required.

The Technology Acceptance Model (TAM) is a widely used framework for understanding user acceptance and adoption of new technologies [4]. Fig. 2 illustrates TAM. The central premise of TAM is that an individual's behavioral intention to use technology is primarily determined by perceived usefulness and ease of use.

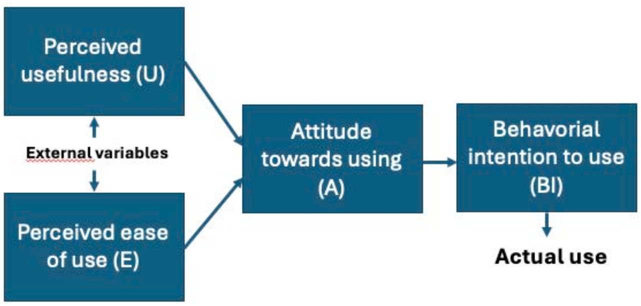

Figure 2. Technology Adoption Model.

Perceived usefulness is the degree to which a person believes using a particular technology helps them achieve their goals. In this case, the goal is to reduce their electricity bills in the long term.

On the other hand, perceived ease of use refers to the degree to which a person believes that using the technology will be free from effort. In other words, will the technology be easy to use to avoid causing frustrations?

These two factors influence an individual's attitude toward technology, shaping their behavioral intention to use it. Ultimately, this behavioral intention is a crucial predictor of technology usage.

Over the years, TAM has been refined and extended to incorporate additional factors that may impact technology adoption, such as subjective norms, perceived risk, and trust. Despite its simplicity, TAM has demonstrated robust predictive power across various technologies and user populations. It is a valuable tool for researchers and practitioners seeking to understand and predict technology acceptance and designing interventions to promote the successful adoption of new technologies. However, potential users need to be aware of the potential of new technology before considering using it. Our project fills this gap by creating awareness among citizens and students about the potential of smart energy solutions.

The following section discusses the awareness campaign. Section III presents a SWOT analysis of the campaign. Section IV introduces an environmental protection course developed as a spin-off from the project. Section V discusses the results. Finally, Section VI provides some conclusions.

II. Awareness Campaign

Kim and Choi [5] define *environmental awareness* as consumers' understanding of environmental issues, including various practices and the connection between certain activities and their environmental impact. However, the main issue is increasing consumers' awareness of their effect on the environment and changing their behavior. If social change affects individual behaviors, marketing is crucial in driving a particular behavior.

Andreasen [6] promotes social marketing as central to influencing and changing behavior. Kotler and Armstrong [7] state that social marketing involves applying marketing concepts and tools "to encourage behaviors that will create individual and societal well-being."

A. Energy awareness campaigns

Hassan et al. [8] reported on an energy awareness campaign at Loughborough University, United Kingdom, where they reduced energy consumption by up to 10% in only 52 days. Their research shows that awareness campaigns can have immediate results related to energy consumption.

Wai et al. [9] proposed a conceptual framework for the energy awareness development process. The framework consists of nine phases, starting with energy awareness stimulus. Our campaign is stimulating citizens (and students) to make better choices.

Khambalkar et al. [10] conducted a survey to assess public attitudes toward renewable energy. The survey showed positive attitudes and a willingness to invest in household renewable energy and energy efficiency. This was a motivation for our campaign.

Szakály et al. [11] examined the relationship between self-reported and actual knowledge of renewable energy sources. The study was done in Hungary, and the results showed that actual knowledge was more favorable than self-reported knowledge. The authors pointed out socio-demographic differences and that young citizens generally had a higher level of awareness. Our campaign saw the same pattern among the participants in training events.

B. Our campaign

An awareness campaign was launched to engage stakeholders and disseminate information on sustainable energy practices. The awareness campaign utilized several communication channels to reach the public, including social media, radio, interviews, videos, flyers, and other promotional materials. Additionally, partners organized kick-off and closing events. Results indicate increased awareness and understanding of sustainable energy practices, greater engagement in initiatives, adoption of sustainable practices at individual, institutional, and community levels, and positive changes in attitudes toward energy consumption and conservation.

During the campaign, 35 training events were held in different locations, and 1146 citizens attended in person. The campaign was mentioned in newspapers and newscasts (TV and radio) 520 times, 287 on a national level and 233 on a local level. The media analytics company mediaTRUST analyzed the campaign. The company evaluated the influence of public relations and marketing communications across diverse media channels by analyzing advertising value and audience engagement, revealing that the campaign effectively reached 1.97 million citizens [12]. Even if there is a big difference between attending a training event and hearing about renewable energy potential on the radio, it still helps increase citizens' awareness. Fig. 3 shows one of the mock-ups used during the training event. The solar panel platform was 3D-printed and automatically adjusts the direction and tilt to optimize energy production. Fig. 4 shows a prototype of a house powered by solar panels, which was used to show the amount of energy produced by the solar panels.

Figure 3. Mock-up of solar panel platform.

Four schools and educational institutions were involved in the campaign to create engagement with the educational community and to foster awareness and understanding of sustainable energy practices among children and educators. More than 300 primary and secondary school children from four different educational institutions participated in the information workshop "Discover the World of Renewable Energy." These institutions include "Samuel von Brukenthal" National High School, Sibiu Secondary School No. 2, "Mihai Viteazu" Secondary School Șelimbăr, and "Ioan Lupaș" High School of Technology Săliște.

Multiple schools and educational institutions participating emphasized the campaign's success in reaching diverse students and educators. This indicates a deliberate effort to actively engage with the educational community and promote knowledge and awareness of renewable energy principles and environmental sustainability from an early age.

During the children's workshop, professors and students from the Engineering Faculty of "Lucian Blaga" University of Sibiu delivered informative sessions covering various themes related to renewable energy and environmental sustainability. These sessions included topics such as solar energy utilization, wind energy conversion, environmentally friendly lifestyles, the importance of nature conservation, energy consumption reduction strategies, stories of renewable energy heroes (for Middle School - Who are the scientists and inventors behind renewable energy?), renewable energy games, storytelling, and experiments and envisioning a future powered by renewable sources.

Figure 4. Prototype of a solar-powered house.

To measure engagement, the following methods were used:

- Attendance records: Keeping track of the number of participants who attended training events, workshops, and Green Week presentations organized as part of the campaign.
- Online analytics: Monitoring website traffic, social media engagement, and the number of unique visitors or followers who viewed campaign-related content online.
- Surveys and registration forms.
- Media coverage and visibility of the campaign.
- Number of schools and educational institutions involved in the campaign.
- Feedback and satisfaction levels from participants and stakeholders.
- Number of resources distributed or shared during the campaign (e.g., informational materials, toolkits, presentations).

III. SWOT ANALYSIS

A SWOT analysis is a planning tool that identifies **S**trengths, **W**eaknesses, **O**pportunities, and **T**hreats. Hunger and Wheelen criticized SWOT analysis for several shortcomings [13]:

- *It generates lengthy lists.*
- *It uses no weights to reflect priorities.*
- *It uses ambiguous words and phrases.*
- *The same factor can be placed in two categories (e.g., a strength may also be a weakness).*
- *There is no obligation to verify opinions with data or analysis.*
- *It only requires a single level of analysis.*
- *There is no logical link to strategy implementation.*

However, the model is simple, easy to comprehend, and well-suited to presenting some critical factors for the campaign's purpose. These are shown in Fig. 5 and further elaborated below.

Figure 5. SWOT analysis.

A. *Strengths*

- Structured Communication Plan: The campaign benefited from a well-defined communication strategy that utilized offline and online channels, including social media, television news, radio, interviews, videos, and promotional materials.
- Broad Reach: According to mediaTRUST, a media analytics company, the campaign reached 298.000 through social media, 201.000 through portals, and 1.47 million through press and radio TV (RTV). The campaign's overall reach amounted to 1.97 million, indicating a wide dissemination of information and engagement within the community [12]. This increased visibility not only enhances awareness of sustainable energy practices but also positions Sibiu County as a leader in environmental sustainability on a larger scale.
- School Engagement: The involvement of four schools and educational institutions facilitated direct interaction with students and educators, fostering awareness and understanding of sustainable energy practices from an early age.
- Expert Involvement: Professors and students from the Engineering Faculty of "Lucian Blaga" University of Sibiu provided informative sessions on renewable energy and environmental sustainability, adding credibility and expertise to the campaign.

B. *Weaknesses*

- Limited Metrics: While attendance records, online analytics, and feedback surveys were utilized, there may be gaps in measuring the campaign's impact comprehensively, particularly in assessing long-term behavior change and adopting sustainable practices.
- Resource Constraints: The campaign faced challenges related to budgetary constraints and limited resources to sustain long-term engagement and follow-up activities beyond the initial outreach efforts.

C. *Opportunities*

- Collaboration: The campaign presents opportunities for collaboration with additional stakeholders, such as local businesses, community organizations, or government agencies, to further amplify its impact and reach.
- Educational Partnerships: Strengthening partnerships with educational institutions can lead to developing tailored curriculum materials and ongoing educational initiatives to embed sustainable energy principles into school curricula.

D. *Threats*

- Sustainability Challenges: Maintaining momentum and sustaining engagement beyond the initial campaign period may pose challenges, particularly without dedicated resources or ongoing support.
- Competition for Attention: The campaign may face competition from other initiatives or priorities competing for stakeholders' attention, potentially diluting its impact or reach.

Overall, the SWOT analysis highlights the extensive awareness campaign's strengths and opportunities while identifying potential weaknesses and threats that may need to be addressed to maximize its effectiveness in promoting sustainable energy practices in Sibiu County.

IV. ENVIRONMENTAL PROTECTION COURSE

In collaboration with Lucian Blaga University, an Environmental Protection course was developed for third-year students specializing in Transport and Traffic Engineering. The course curriculum, spanning 14 weeks with 28 hours of instruction and 14 hours of laboratory work, focused on fundamental topics related to energy resources, electricity production, energy consumption, and methods for assessing energy efficiency. This course aimed to equip

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students with the knowledge and skills necessary to address environmental challenges within their field of study. The course is already in its second edition (ongoing). Because of its interest, it was divided into several application modules, which were then presented to students from several specializations, depending on the area of interest and specialization.

The students will know how to collect and analyze data from a quantitative and qualitative point of view, from various alternative sources, and from the literature in the field to formulate arguments, decisions, and concrete approaches in energy efficiency applications. This will lead to training and stimulating the awareness and sensitivity of future engineers to environmental issues.

LBUS proposed a strategy to attract young students to green energy and its practical applications by organizing the interactive contest "Mock-up for energy efficiency systems." During the laboratory hours, the students participating in the Environmental Protection course will make five Mock-ups with a freely chosen theme: Innovative solutions to reduce energy consumption.

The expected results from this course are:

- Increased participation and engagement: Track the number of students enrolled in the course compared to previous years to assess increased interest.
- Completion rates: Monitor the percentage of students who complete the course to gauge its effectiveness.
- Performance improvement: Assess changes in student performance through pre- and post-course evaluations or exams.
- Mock-up creation: Evaluate the quality and creativity of the mock-ups produced by students during laboratory sessions.
- Feedback analysis: Analyze feedback from students regarding the course content, structure, and overall learning experience to identify areas for improvement.
- Adoption of energy-efficient practices: Measure how students apply knowledge gained from the course in real-world contexts, such as implementing energy-saving measures or promoting sustainability initiatives within their communities.

V. DISCUSSIONS

This section discusses some challenges in conducting this kind of energy awareness campaign.

One significant challenge is related to *awareness and engagement*. Despite the comprehensive strategy outlined in the paper, reaching and engaging all stakeholders, including community members and businesses, may require some clarification. Overcoming barriers to awareness and participation requires ongoing efforts to tailor communication strategies and outreach activities to diverse audiences. It is essential to employ a variety of communication channels and messaging techniques to ensure that information reaches and resonates with all segments of the population.

Another challenge is *resource constraints*. Implementing the multifaceted interventions described in the paper may require significant resources, including funding, expertise, and logistical support. Securing adequate resources and coordinating efforts across various stakeholders may present logistical challenges. To ensure the success and sustainability of these initiatives, it will be essential to mobilize support from government agencies, non-profit organizations, and private sector partners.

Finally, encouraging *behavior change* towards sustainable energy practices can be complex. Addressing entrenched habits, attitudes, and cultural norms may require targeted interventions, ongoing education, and community engagement. It is essential to recognize that behavior change takes time and may require a combination of incentives, regulations, and social norms to promote sustainable practices effectively.

Fig. 5 illustrates these challenges. The multifaceted approach outlined in this paper represents a valuable framework for promoting sustainable energy practices. By addressing these challenges head-on and leveraging the strategy's strengths, stakeholders can work together to overcome barriers and achieve meaningful progress toward a more sustainable future. Ongoing evaluation and adaptation of strategy will ensure that interventions remain relevant and effective in the face of evolving needs and circumstances.

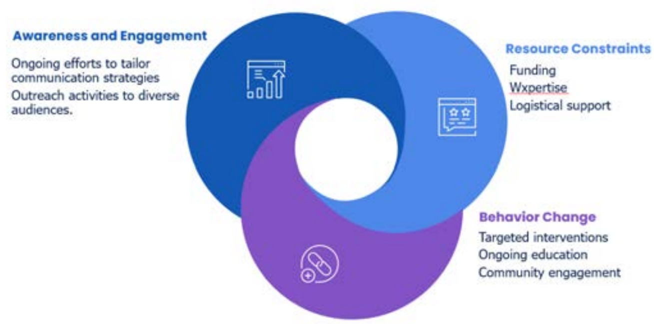

Figure 6. Challenges of the project implementation.

VI. CONCLUSIONS

A digital society is where digital transformations contribute to solving more significant societal problems. Reducing energy consumption and introducing renewable energy sources are essential to society and individual households. Smart energy solutions are available, but to be adopted, they must create value for the user and be easy to use. However, adoption requires awareness of smart energy solutions, from installing renewable energy to utilizing peak shaving and load shifting. However, a prerequisite to the adoption of technology is awareness of the possibilities of the technology. Therefore, this kind of awareness campaign presented here is essential.

This project is unique because Sibiu County took leadership in raising awareness about renewable energy and energy efficiency and partnered with academia to create an awareness campaign.

The project underscores the importance of behavior change in achieving sustainable energy goals. Encouraging individuals and businesses to adopt energy-saving practices requires addressing entrenched habits, attitudes, and cultural norms. Future efforts should focus on providing incentives, education, and support to facilitate behavior change and promote a culture of sustainability.

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The prototype of the solar-powered house in Fig. 4 was created by Nichita-Traian Chicioroagă, a student at Lucian Blaga University of Sibiu, as a student project.

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