

Digitalisation of Highly Regulated Sectors: Understanding Enablers for Digital Technology Adoption

Cezara-Lidia JALBA^{a,1}, Dave CLARK^a, Susan LATTANZIO^b, Muhammad BASIR^b
and Linda NEWNES^b

^a*Nuclear Decommissioning Authority, United Kingdom*

^b*University of Bath, Bath, United Kingdom*

Abstract. Digital technologies have the potential to improve processes, increase productivity, and materialise new benefits. Despite these benefits, heavily regulated sectors such as the energy sector, characterised by conservatism and a low appetite for risk, encounter obstacles hindering their adoption. This is significant. If digital technologies could be more extensively used in these sectors it might realise considerable economic, environmental, and societal value. Within this paper we present a case study of the Connected Infrastructure project – a successful digital technology project which was conducted by the UK’s Nuclear Decommissioning Authority (NDA). We conduct a workshop with key project stakeholders and use this to identify and rank barriers to digitalisation within the nuclear sector. These barriers are used to structure a discussion to elicit enablers – factors considered to have contributed to the successful implementation of the project. Through thematic analysis ten enabler themes are identified. These are mapped to the transdisciplinary hierarchical system proposed in the seminal work of Jantsch. The results show that both barriers and enablers encompass three levels of the hierarchy (purposive, normative, and pragmatic). No enablers are found to map to the empirical (fundamental science) level. The conclusions emphasise the significant impact of multilevel coordination, which is a distinguishing factor of transdisciplinary approaches and suggest creating a repository of successful technology implementation projects, in relatable contexts, as a practical strategy for improving adoption rates. Future work will look to create and validate guidelines for enabling digital technology uptake in the nuclear sector.

Keywords. Transdisciplinary engineering, nuclear, digital technology, connected infrastructure, change management.

Introduction

Digital technologies bring with them the promise of considerable benefit to industry and societal benefits. According to the World Economic Forum, the adoption of digital technologies during the period 2016 to 2026 is estimated to have a value of \$100 trillion [1]. Despite their potential, technologies often encounter barriers to widespread adoption [2]. This reluctance is particularly pronounced in highly regulated industries like the nuclear sector, where risk tolerance is often low, and regulations are stringent [3]. This

¹ Corresponding Author, Email: cezara-lidia.jalba@nda.gov.uk.

is significant because if these sectors refrain from adopting digital technologies, they may overlook opportunities such as cost reduction, enhanced safety, and decreased environmental impact.

In addressing the challenge, the academic literature has primarily focused on identifying barriers to the adoption of digital technologies. The literature shows that barriers to adoption encompass organisational, technical, and people factors. While understanding of the barriers is crucial for tackling the challenge of technology adoption, it only represents one aspect of the equation – what impedes technology adoption. Currently, little consideration has been given to understanding the enablers that facilitate adoption.

In this study we aim to identify and characterise the factors that support the adoption of digital technologies in highly regulated industries. We present a case study of the Connected Infrastructure project (CI), led by the UK's Nuclear Decommissioning Authority (NDA) at the Nuclear Restoration Services (NRS) Dounreay site. Through a workshop involving key stakeholders of the project, we identify and prioritise the barriers to digitalisation faced in the nuclear sector. These barriers serve as a framework for discussion to uncover the enablers that have facilitated the project. To understand the disciplinary nature of these enablers, we discuss them in the context of the seminal work of Jantsch's, and the transdisciplinary hierarchical system [4].

The paper is structured as follows. First, the background literature including an introduction to barriers and enablers is presented (Section 1). Next, the case study and the approach used within the workshop is described in detail (Section 2). The results are presented and discussed (Section 3). Finally, conclusions are formulated (Section 4) and future work proposed (Section 5).

1. Background

Digital technologies promise significant benefits, including cost reduction, integration, and mass customisation. While some organisations have successfully leveraged these potential benefits, others have struggled to realise them. This disparity is attributed to factors that either positively or negatively influence the adoption of digital technologies. In this context three types of factors have been discussed: 'drivers' which motivate organisations to undergo digital transformation [5], 'barriers' which impede progress [6] and 'enablers' which facilitate technology adoption [7]. While appreciating that drivers play a critical role in motivating organisations to undertake digitalisation projects, our research sought to examine the broader landscape of factors, including barriers and enablers, that contribute to the outcome of technology adoption projects.

1.1 *Barriers to the adoption of digital technologies*

A substantial body of literature has addressed the barriers to digitalisation. Studies have identified numerous obstacles hindering the implementation of technologies, including, but not limited to, the lack of a skilled workforce [8], conflicts among workers due to changing working environments [9], shortage of financial resources [10], concerns about data security [5], low levels of standardisation [11], and poor integration [12].

Specific to the manufacturing sector the Made Smarter Review [2] conducts a detailed study into the factors affecting the uptake of digital technologies. They conclude that barriers to adoption are multifaceted and highlight the need for comprehensive strategies to address these challenges effectively.

Barriers in technology adoption exhibit complex characteristics, influencing the adoption process individually and collectively. Chauhan et al. [13] highlights the importance of understanding the intricate interplay between internal resources and external contingencies (e.g., laws and regulations) on organisational digitalisation efforts. This underscores the complex nature of barriers and highlights that internal factors such as organisational culture, resource allocation, and strategic alignment play a crucial role in shaping technology adoption outcomes.

1.2 Enablers to the adoption of digital technologies

In contrast to the barriers to adoption of digital technologies, enablers have received considerably less attention. Within the academic literature much of the discussion around enablers centres not on factors which can help the adoption of digital technologies, but on the technology itself as the primary ‘enabler’. In this regard digital technologies, such as additive manufacturing, the internet of things, augmented reality, robotics, and cyber-physical systems, are found to serve as the main enablers for improving productivity [14], meeting customer demands [15], optimising resources [16], and gaining competitive advantage [17].

This focus on ‘technology as an enabler’ is supported by a study conducted by Ng and colleagues [18]. Based on an extensive literature review the authors provide thematic categorisation of eight enablers of digital technologies – actors, resources, conditions, attributes, processes, artifacts, values, and risks. Notably, six out of these eight identified enablers are either technology itself or related to technology development or design. Although reinforcing the ‘technology as an enabler’ narrative, the study highlights that enablers related to people responsible for planning (actors) are found to have strong influence on the adoption process. They find that whilst technology is evidently an essential enabler, as digitalisation is impossible without it, understanding what other factors aid in the successful implementation is of most importance.

1.3 Digital technologies in highly regulated industries

Although some sectors such as retail are embracing new digital technologies, others such as highly regulated sectors are lagging. Highly regulated industries (HRI) come directly under the governance of government [19]. According to UK’s Regulatory Futures Review [20], industries such as nuclear, pharmaceutical, civil aviation, and water are classified as highly regulated industries.

The energy sector operates within a highly regulated environment with stringent safety and security standards, amplifying the barriers of integrating new technologies [3]. These barriers, including resilience [21], policy constraints [22], uncertainties [23], and public perception [24], create complexities in adoption of innovative solutions. Among the energy sector, the nuclear industry is subject to more scrutinised and stricter

legislative and regulatory oversight due to the potentially catastrophic consequences of mishaps or failures [25].

The stringent regulations governing these HRIs exacerbates the disparity, as common or general frameworks and guidelines become less suitable [26]. In such highly regulated sectors, the divergence in the barriers becomes more pronounced, necessitating tailored approaches to digitalisation.

1.4 Summary

To date considerable effort has been undertaken to explore and categorise the barriers influencing technology adoption. These have been found to be multi-faceted, encompassing both technology and non-technology factors. Within the literature less consideration has been given to the enablers of digitalisation. Where enablers have been considered the focus has tended to be on the technology as an enabler to value realisation, rather than understanding the factors which have facilitated the adoption of digital technology. Digitalisation of highly regulated industries such as the nuclear sector is particularly challenging. Despite this there are a lack of case studies which have focused on understanding the enablers which have facilitated successful digitalisation projects in this area.

2. Approach

Within this work we present a case study of the Connected Infrastructure digitalisation project which was undertaken at the NRS Dounreay site. The case study focusses on a workshop conducted with key members of the project team. The objectives of this work were:

1. To identify and rank the barriers to digitalisation within the nuclear sector.
2. To identify the enablers which have contributed to the success of the CI project.
3. To map how these enabling factors align with Jantsch's transdisciplinary hierarchical system.

2.1 The Connected Infrastructure Project

The NDA is a non-departmental public body created by the Energy Act 2004 and sponsored and funded by the Department for Energy, Security and Net Zero [27]. Their remit is to lead the clean-up and decommissioning work at 17 nuclear sites on behalf of government. The challenge faced by the NDA in decommissioning sites is how to improve safety, performance, and reliability to advance mission delivery in a complex environment of aged infrastructure. It is in this context that the NDA are looking towards increased use of digital technologies.

The NDA has adopted an approach, known as OneNDA, which involves working closely with the operating companies responsible for managing the sites. The OneNDA Digital Asset Management Roadmap outlines a strategic plan to improve asset management and enhance processes and capabilities through digitalisation. In doing so it aims to strengthen and align OneNDA's information and decision-making practices.

The roadmap has three pillars: Enterprise Asset Management, Asset Intelligence and Connected Infrastructure. The CI project aims to remove the requirement for manual data capture, human effort, and plant walkdowns through a connected Information Technology (IT) / Operational Technology (OT) solution. This means that site and asset information will be visible, enabling intelligent decision making, improving safety, and reducing the likelihood of performance failure. The CI project commenced in November 2022 and is being delivered in phases. Phases 1 and 2 are complete. Phase 3 is currently running and is due to complete in the 2024/25 financial year. The project is considered by the NDA to be a success on two fronts – (1) benefits delivered (2) as a use case for digitalisation within the nuclear sector.

As part of the CI project planning stage eleven key stakeholders were identified using a power influence matrix. These incorporate representatives from the NDA, Dounreay site, management consultants involved in the delivery, and the nuclear regulator. Their roles encompass digital technology experts, project management, and energy regulation, reflecting a convergence of disciplines. It is these stakeholders who were invited to participate in the workshop.

2.2 *The workshop*

The workshop was undertaken with the key stakeholders identified within the project planning stage. Being closest to the project they were viewed to have the greatest insights in terms of how it has run so far and have a say in its future direction. The workshop was run in the format of a facilitated virtual meeting with tasks being run utilising an interactive Padlet virtual environment [28]. The five tasks were:

- Task 1: A list of eighteen barriers to the adoption of digital technologies in the energy sector identified by Wang et al. [3] was uploaded to Padlet. The participants were asked to rate the relevance of these barriers within the nuclear sector using a Likert scale (1 not significant – 5 very significant).
- Task 2: The participants were asked if there were any barriers missing from the list. Any additional barriers were captured on the Padlet by the workshop facilitator.
- Task 3: Following the approach in Task 1, the participants were asked to rank these additional barriers for significance.
- Task 4: The participants were asked to think about what they did in the CI project to remove or reduce these barriers. Comments regarding enablers were captured against each barrier by the workshop facilitator.
- Task 5: The participants were asked if there were any enablers missing from the list. The workshop facilitator captured any additional enablers on the Padlet i.e., enablers that do not directly map to the barriers identified in Task 1 & 2.

2.3 *Mapping of the enablers to Jantsch's Transdisciplinary Hierarchical System*

Jantsch's seminal paper [4] introduced a transdisciplinary hierarchical framework comprising four levels: purposive, normative, pragmatic, and empirical. It advocates for engagement across all these levels for effective transdisciplinary work. In our analysis,

we adapted the interpretation of these levels presented by Lattanzio et al. [29] to suit the industrial context under study:

- **Purposive:** Pertains to the clarity of meaning and value.
- **Normative:** Refers to social systems reflecting societal values and norms, such as laws, standards, and cultural practices.
- **Pragmatic:** Involves the practical application of scientific knowledge and disciplines.
- **Empirical:** Relates to fundamental science and principles.

Using thematic analysis [30], we initially identify themes within the enablers and then align these with the hierarchy. This approach allows us to assess not only the hierarchical level of the enablers but also their potential to support transdisciplinary collaboration effectively.

3. Results and Discussion

Of the 11 key stakeholders identified within the CI project, seven (64%) attended the workshop. These seven included in one case a delegated representative rather than the named individual (Table 1).

Table 1. Workshop participants.

Participant	Professional Speciality	Organisation
1	Engineering Manager	NRS Dounreay
2	Cyber Security Specialist	NRS Dounreay
3	Director	NRS Dounreay
4	IT Specialist	NRS Dounreay
5	Cyber Security Consultant	KPMG
6	Project Management Consultant	KPMG
7	Asset Management & Continuous Improvement (Digital) Manager	NDA

3.1 Barriers to digitalisation in the nuclear sector

In addition to the eighteen barriers to the adoption of digital technologies identified by Wang et al. [3], the participants identified another fourteen barriers. Ranking identified a range from 4.57 (understanding of beneficial use cases) to 2.14 (market risk). The identification of 'understanding of beneficial use cases' as the highest ranked factor is notable. It seems unrelated to the 'high-risk' nature of the business but rather pertains to understanding potential opportunities. The low ranking of market risk was unsurprising given the non-competitive nature of the organisations involved.

The top five ranked barriers are shown in Table 2 in order of importance. The barriers noted with an asterisk (*) are those which do not appear in the original paper. Among the barriers ranked 1-5, we observe a mix of technical issues (e.g., significant technology gaps and security concerns), people-related challenges (e.g., lack of

stakeholder awareness and specialists in digital technology implementation), and organisational factors (e.g., limited understanding of beneficial use cases, insufficient business integration and alignment, inadequate budget allocation for new technologies). These findings are consistent with existing literature and underscore the multidimensional nature of barriers to adoption of digital technology. Importantly, they demonstrate that the most significant barriers identified by participants are not solely technical. This insight suggests that if barriers extend beyond technical aspects, enablers must also be broadened accordingly.

Table 2. Top 5 ranked barriers to adoption of digitalisation within the nuclear sector.

Rank	Rating	Barrier
1	4.57	Understanding of beneficial use cases*
2	4.43	The security issues
3	4.29	Shortage of specialists associated with digital technology implementation in the energy industry
4=	4.14	Lack of business integration & alignment*
4=	4.14	Poor budget allocation to implement new technologies*
5=	4.00	Shortage of stakeholder awareness
5=	4.00	Big gap in technologies from old systems to new*

3.2 Enablers within the Connected Infrastructure Project

The purpose of first identifying the barriers within the workshop was to facilitate more structured discussions of enablers. Accordingly, the participants were asked to consider the barriers and discuss as a group the enablers which they considered had been applied within this particular project. The workshop participants identified 68 enablers which mapped to the barriers. In addition, five enablers did not map directly to the barriers. Removing duplicates, 60 discreet enablers remained. Similar to barriers to digitalisation, the enablers were also found to be multidimensional and include technical (e.g., applying minimum viable technology approach, use of automation, minimising data collection) and non-technical factors (e.g., site culture, successful stakeholder communication, taking a pragmatic approach).

Thematic analysis grouped the 60 enablers in to ten themes. These were mapped to the four levels (purposive, normative, pragmatic, and empirical) identified in Jantsch's [4] transdisciplinary hierarchical system (Table 3).

Table 3. Enablers of digitalisation identified themes.

Enabler theme	Description	Transdisciplinary Hierarchical level
Stakeholders	Involvement of the right stakeholders at the right time in the right place, with proactive relationship management approach.	Overarching cooperation and coordination
Collaboration	Proactive and flexible approach to working together with the right stakeholders, leaders and decision makers, supply chain, and subject matter experts. Willingness to share resources.	Overarching cooperation and coordination
Communication	Proactive approach to documenting project, sharing learning from experience (LFE), and communicating with stakeholders.	Overarching cooperation and coordination

Promotion	Promotion of the project to the wider community by leaders, users, and delivery team.	Overarching cooperation and coordination
Benefits	Incentives to create and take advantage of benefits.	Purposive
Culture	Importance of the right culture for project success, including having motivated staff.	Normative
Rules and Regulations	Following all rules and regulations, implementing right security strategies.	Normative
Use Case	Choosing a strong use case to ensure pilot project success and benefits demonstration.	Pragmatic
Planning	Approach to planning in terms of strategic approach, financial, and governance structures.	Pragmatic
Technical	Use of the right technology in the site context, with a minimum viable product and minimum data transmission approach.	Pragmatic

The results of the analysis demonstrate a spread of the enabler themes across three (purposive, normative, and pragmatic) of the four levels of the hierarchy. Interestingly, no themes were mapped to the ‘empirical’ level. This is understandable as given the risk averse nature of the industry only proved technologies would be implemented and as such would not involve consideration of the fundamental science and principles.

Of note is that although six of the themes were mapped to a specific level, the remaining four (stakeholders, collaboration, communication, and promotion) were not about the nature of enablers but more about having cooperation and coordination across the levels. This multilevel coordination is the key element of transdisciplinarity and what distinguishes it from other disciplinary ways of working [4].

4. Conclusion

The potential benefits of digital technologies for both industry and society are significant. However, barriers often impede their widespread adoption, especially in heavily regulated sectors. While understanding these barriers is crucial, it's equally important to consider factors that can facilitate adoption. This study addresses this gap by identifying and characterising the factors supporting digital technology adoption in a highly regulated industry.

Our analysis elicited and ranked the barriers to digitalisation within the nuclear sector. These barriers encompass organisational, technical, and cultural factors, and supports the findings of previous literature that barriers are multidimensional. Notably, the highest-ranked barrier – ‘understanding of beneficial use cases,’ underscores the significance of identifying opportunities beyond technical issues and emphasises the necessity for practical strategies to address this aspect.

Similarly, our exploration of enablers uncovered a diverse set of factors contributing to successful adoption. Identifying themes and mapping these to Jantsch's transdisciplinary hierarchical system uncovered some significant insights. Whilst the themes mapped to purposive, normative, and pragmatic levels, none directly related to empirical factors. This reflects the industry's risk-averse nature and the requirement for technical solutions to have been proven before they would be implemented within the sector. It would suggest that establishing a library of successful technology implementation projects in relevant contexts would be a practical route to enhancing

adoption. Additionally, it highlights the significance of multilevel coordination – a distinguishing feature of transdisciplinary approaches.

5. Future Work

The aim of the NDA is to develop practitioner guidelines to support the successful adoption of digital technologies. Achieving this goal necessitates collaboration between academia and industry to ensure that the guidelines are both rigorous and practical for real-world application. This study contributes to this endeavour. To enhance accessibility, it is anticipated that the research is “translated” into formats (e.g., webinars, blogs, and industry presentations), better suited for an industry audience, enabling the NDA to share findings and gather insights from stakeholders.

In terms of academic pursuits, future research includes a project involving a University of Bath MEng final-year student. This project will focus on identifying the enablers of Enterprise Asset Management, another pillar of the OneNDA Digital Asset Management Roadmap, serving to corroborate the findings of this study. It is important to emphasise that this work is geared towards creating impact. Therefore, alongside traditional research, emphasis will be placed on facilitating opportunities for co-creation of insights.

Acknowledgement

The work reported in this paper was supported by the Made Smarter Innovation: Centre for People-Led Digitalisation, at the University of Bath, University of Nottingham, and Loughborough University. The project is funded by the Engineering and Physical Sciences Research Council (EPSRC) Grant EP/V062042/1.

References

- [1] World Economic Forum, *Digital Transformation of Industries Demystifying Digital and Securing \$100 Trillion for Society and Industry by 2025*, Switzerland, 2016.
- [2] J. Maier, *The Made Smarter Review*, UK Government, 2017.
- [3] W. Wang, Y. Chen, Y. Wang, M. Deveci, S. Moslem, and D. M. Coffman, Unveiling the implementation barriers to the digital transformation in the energy sector using the Fermatean cubic fuzzy method, *Applied Energy*, vol. 360, p.122756, 2024.
- [4] E. Jantsch, Inter-and transdisciplinary university: A systems approach to education and innovation, *Policy Sciences*, Mar 1970, vol. 1, no. 1, pp. 403-428,
- [5] J. Stentoft, A. Dsbøll, K. Wickstrøm, K. Philipsen, A. and Haug, Drivers and barriers for Industry 4.0 readiness and practice: empirical evidence from small and medium-sized manufacturers, *Production Planning & Control*, May 2021, vol. 32, no. 10, pp. 811-828.
- [6] P. Kumar, P., R. K. Singh, and V. Kumar, Managing supply chains for sustainable operations in the era of industry 4.0 and circular economy: Analysis of barriers, *Resources, Conservation and Recycling*, Jan 2021, vol 164, pp.105215.
- [7] L. D. Piovesan, R. G. G. Caiado, R. S. Santos, and A. M. T. Thomé, Barriers, Enablers and Base Industry 4.0 Technologies of Digital Transformation in Supply Chains: An Inter-Country Comparison, *International Joint conference on Industrial Engineering and Operations Management*, Switzerland, Cham: Springer Nature 2023, pp. 521-539.
- [8] D. Kiel, C. Arnold, and K. I. Voigt, The influence of the Industrial Internet of Things on business models of established manufacturing companies—A business level perspective, *Technovation*, Dec 2017, vol. 68, pp.4-19.

- [9] M. M. Babu, M. Rahman, A. Alam, and B. L. Dey, Exploring big data-driven innovation in the manufacturing sector: evidence from UK firms, *Annals of Operations Research*, Apr 2021, vol. 333, pp. 1-28.
- [10] J. Gallien, N. H. Z. Leung, and P. Yadav, Inventory policies for pharmaceutical distribution in Zambia: Improving availability and access equity, *Production and Operations Management*, Jul 2021, vol. 30, no. 12, pp. 4501-4521.
- [11] S. Mukhuty, A. Upadhyay, and H. Rothwell, Strategic sustainable development of Industry 4.0 through the lens of social responsibility: The role of human resource practices, *Business Strategy and the Environment*, Feb 2022, vol. 31, no. 5, pp. 2068-2081.
- [12] S. Li, G. C. Peng, and F. Xing, Barriers of embedding big data solutions in smart factories: insights from SAP consultants, *Industrial Management & Data Systems*, Jun 2019, vol. 119, no. 5, pp. 1147-1164.
- [13] C. Chauhan, A. Singh, and S. Luthra, Barriers to industry 4.0 adoption and its performance implications: An empirical investigation of emerging economy, *Journal of Cleaner Production*, Feb 2021, vol. 285, pp. 124809.
- [14] R. Agrifoglio, C. Cannavale, E. Laurenza, and C. Metallo, How emerging digital technologies affect operations management through co-creation. Empirical evidence from the maritime industry, *Production Planning & Control*, Oct 2017, vol. 54 no. 16, pp. 1298-1306.
- [15] H. Fatorachian, and H. Kazemi, A critical investigation of Industry 4.0 in manufacturing: theoretical operationalisation framework, *Production Planning & Control*, Jan 2018, vol. 29, no. 8, pp. 633-644.
- [16] P. Helo, and Y. Hao, Cloud manufacturing system for sheet metal processing, *Production Planning & Control*, May 2017, vol. 28, no. 6-8, pp. 524-537.
- [17] N. Karia, Knowledge resources, technology resources and competitive advantage of logistics service providers, *Knowledge Management Research & Practice*, Oct 2018, vol. 16, no. 4, pp. 451-463.
- [18] M. S. Ng, D. Hall, M. Schmailzl, T. Linner, and T. Bock, Identifying enablers and relational ontology networks in design for digital fabrication, *Automation in construction*, Dec 2022, vol. 144, pp. 104592.
- [19] Y. Chen, C. H. Chen, and Y. T., Wu, An assessment of the relationship between channel stuffing and related party transactions: evidence from China's listed companies, *International Journal of Disclosure and Governance*, Jun 2019, vol. 16, pp. 116-127.
- [20] GOV.UK, "Regulatory Futures Review". N.A., 2017.
https://assets.publishing.service.gov.uk/media/5a8189f2e5274a2e87dbe2a3/Regulatory_Futures_Review.pdf
- [21] M. Andoni, V. Robu, D. Flynn, S. Abram, D. Geach, D. Jenkins, P. McCallum, and A. Peacock, Blockchain technology in the energy sector: A systematic review of challenges and opportunities, *Renewable and sustainable energy reviews*, Feb 2019, vol. 100, pp. 143-174.
- [22] P. Chen, B. Cai, M. Wu, and Y. Zhao, Obstacle analysis of application of blockchain technology in power data trading based on improved DEMATEL-ISM method under fuzzy environment, *Energy reports*, Nov 2022, vol. 8, pp. 4589-4607.
- [23] W. Guo, N. M. F. Qureshi, M. A. Jarwar, J. Kim, and D. R. Shin, AI-oriented smart power system transient stability: the rationality, applications, challenges and future opportunities, *Sustainable Energy Technologies and Assessments*, Mar 2023, vol. 56, pp. 102990.
- [24] S. Gawusu, X. Zhang, A. Ahmed, S. A. Jamatutu, E. D. Miensah, A. A. Amadu, and F. A. J. Osei, Renewable energy sources from the perspective of blockchain integration: From theory to application, *Sustainable Energy Technologies and Assessments*, Aug 2022, vol. 52, pp. 102108.
- [25] S. Hanger-Kopp, J. Lieu, and A. Nikas, *Narratives of Low-Carbon Transitions*, Routledge: Taylor & Francis, 2019.
- [26] J. B. Roca, and E. O'Sullivan, Seeking coherence between barriers to manufacturing technology adoption and innovation policy, Dec 2020, *International journal of production economics*, vol. 230, 107818.
- [27] Nuclear Decommissioning Authority. Retrieved from
GOV.UK:<https://www.gov.uk/government/organisations/nuclear-decommissioning-authority> (last accessed May 2024)
- [28] Padlet. <https://padlet.com/> (last accessed May 2024)
- [29] S. Lattanzio, E. Carey, A. Hultin, R. Imani Asrai, M. McManus, N. Mogles, G. Parry, and L. Newnes, L, Transdisciplinarity Within the Academic Engineering Literature, *International Journal of Agile Systems and Management*, 2020, vol. 13, no. 2, pp. 213-232.
- [30] V. Braun, and V. Clarke, Using thematic analysis in psychology, *Qualitative research in psychology*, Jul 2006, vol. 3, no. 2, pp. 77-101.