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The Symbiosis Of Decarbonization And Digitalisation: A Sustainable Future For Organizations

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Abstract

In an era increasingly defined by the relentless advance of climate change, the imperative for sustainable transformation has emerged as a central concern for global organizations. For this transformation the intertwined concepts of decarbonization and digitalisation can offer a blueprint for a sustainable future. Decarbonization, aimed at reducing carbon-based emissions, is critical in lessening the ecological footprint of businesses. Yet, achieving decarbonization is not a solitary journey but one that necessitates the integration of digitalisation as a pivotal facilitator, enhancing the efficiency and efficacy of this transition. However, the challenge for organizations lies in devising and executing appropriate strategies for this transformation. Within the framework of the Roadmap.SW research project, a methodology is being developed to aid utilities in accelerating their decarbonization and digitalisation efforts. This involves initially assessing the organization's current capabilities in digitalisation and decarbonization to then establish a desired future state and to finally outline steps for implementation. This research work extends the acatech Industry 4.0 Maturity Index to encompass additional design domains, incorporating capabilities and maturity levels specific to decarbonization. At the same time, the focus of the target group is changing. While the original model focussed on Industry 4.0, i.e. the transformation of manufacturing companies, the extension focuses on municipal utilities. This approach not only charts a course for sustainable organizational transformation but also underscores the critical interplay between reducing carbon emissions and embracing digital advancements.

Keywords

Industry 4.0; Digital Transformation; Decarbonization; Maturity Assessment; Sustainability; Roadmap;

1. Introduction

In addition to companies' challenges posed by digital transformation, climate change is manifesting itself as an omnipresent phenomenon that has far-reaching effects on various areas of society. As a result, organizations in various sectors are being forced to not only rethink their digital transformation strategies, but also to develop measures to make their activities more sustainable [1–3]

The challenge of driving forward both decarbonization and digitalisation does not only affect industrial companies, but also extends to municipal utilities and energy suppliers. Tackling climate change therefore requires a comprehensive commitment and cross-sector cooperation to ensure a sustainable and resilient future. Sustainability is often divided into three pillars: economic, environmental, and social [4]. Given the urgency of climate change, decarbonization is becoming increasingly important. Decarbonization can be understood as a component of sustainable development and can be assigned to the environmental pillar. Decarbonization refers to the process of reducing or eliminating carbon emissions, particularly by switching from fossil fuels to renewable energy sources and improving energy efficiency [5]. Organizations have long

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focused on digitalisation to drive efficiency improvements and foster innovation. Currently, a synergistic relationship between decarbonization and digitalisation is emerging. By integrating efforts in both areas, organizations can unlock additional efficiencies and spur innovative solutions, thereby amplifying their impact on sustainability. Digital technologies are seen as the key to implementing measures to reduce carbon emissions [6–8,8]. One example of this is the use of Internet of Things (IoT) technologies to optimize energy consumption and efficiency in industrial processes. By implementing IoT sensors, companies can collect and analyse real-time data on energy consumption to identify and optimize inefficient operations, ultimately leading to a reduction in carbon emissions [9,10]. Given this link, it is imperative to consider both issues in the context of a holistic strategy to leverage synergies and develop effective solutions to address environmental challenges because without digitalisation, achieving significant carbon reduction goals becomes significantly more challenging. Although it must be considered that digital technologies themselves also produce CO2 emissions, scientists agree that the potential for Decarbonization is far greater [11,3].

This requires an integrated approach that fully exploits the potential of digital innovation to promote decarbonization. However, creating or implementing an integrated approach that combines digitalisation and decarbonization is a challenge for many companies and organizations [6,8]. The topics are often located in different specialist areas, creating a kind of silo mentality that makes collaboration difficult. The integration of digitalisation and decarbonization is associated with a high level of complexity and the costs of technological changeover. In addition, the implementation of holistic strategies requires a rethink at management level; a clear vision is needed to fully exploit the potential of the digital transformation to support decarbonization.

This paper presents the initial results of the Roadmap.SW research project. Roadmap.SW is pursuing the development of the municipal utility of the future by combining the two components digitalisation and decarbonization. The aim is to develop a model that reflects the current maturity level of digitalisation and decarbonization of a municipal utility. Transformation roadmaps are derived based on this current state to achieve the highest level of maturity as the target state (municipal utility of the future). The maturity level is described by various capabilities. Capabilities play a central role in transformation processes, as they form the basis for successfully managing change. They enable those involved to understand and accept change. This paper shows the capabilities, divided into five design areas, that are crucial to drive digitalisation and decarbonization in municipal utilities. The aim is to combine the decarbonization and digitalisation components in a maturity model for the first time. The model is applied here to municipal utilities.

1.1 Background

The idea of determining the level of maturity through skills and deriving transformation roadmaps is based on the "acatech Industry 4.0 Maturity Index" (I4.0MI). The I4.0MI is a model that accompanies companies on their path to Industry 4.0 with the aim of becoming a digitalised, agile company [12]. The path outlined comprises six maturity levels, each of which is described by capabilities and increases the benefits as digitalisation progresses. The model identifies four design areas (resources, information systems, culture, organisational structure) that provide a comprehensive view and structure the capabilities that a company must have. Companies can use the I4.0MI as a useful tool to drive forward the digital transformation of their organization.

The index is applied in three phases:

1. Determination of the current Industry 4.0 development stage: This is where the company's existing capabilities are analysed and evaluated.

2. Gap-analysis**:** Based on the corporate strategy, the targeted development stages are determined, and the required capabilities are identified.

3. Identification of specific measures: Measures are derived to build the identified capabilities, and these are localised in a roadmap.

Implementing the model necessitates not only technological changes, but also organizational and cultural adjustments within companies. It is crucial to cultivate an open communication culture and actively involve employees in the transformation process. In conclusion, the model provides a structured approach to implementing Industry 4.0 that supports companies in successfully shaping their digital transformation and strengthening their competitiveness.

2. Methodology

As previously mentioned, the paper uses the I4.0MI as a framework for the development of transformation roadmaps. To this end, the basic logic of the I4.0MI, with its three phases and the maturity levels described by capabilities, is adopted. However, the I4.0MI focuses primarily on digitalisation in manufacturing companies. The index is now being expanded to include capabilities that describe and can further develop the maturity level of decarbonization. The user group here is municipal utilities.

The method follows a three step approach:

1. Identification of design areas: As the I4.MI design areas were not sufficient, these were redefined. Utilizing the OSTO system model, which offers a comprehensive framework for analysing complex systems like organizations, the design areas were adjusted. Design areas were identified based on discussions, distinguishing between contributions to digitalisation, decarbonization, or both. For the identification, an exchange was sought with an expert in the OSTO model and the design areas were validated.
2. Adjustment of Capabilties: The capabilities that previously related purely to the production environment have been removed or adapted to the context of municipal utilities. Capabilities relating to decarbonization were also added. The capabilities were adapted based on literature research and exchanges with decarbonization experts.
3. Validation of Capabilties: The resulting list of capabilities with varying maturity levels was validated through a series of interviews and workshops involving representatives from municipal utilities. Six expert groups were formed, each organizing workshops to validate four to eight relevant capabilities. In the validation, the entirety of the capabilities was checked for completeness, the naming of the capabilities and the respective maturity levels within a capability were discussed.

3. Research Results

In the following, the results of the research will be presented.

3.1 State of the Art

Despite the growing interest in integrating decarbonization and digitalisation into maturity assessments for manufacturing companies, there is a significant research gap in comprehensively assessing digitalisation and decarbonization as an intertwined concept [13]. Furthermore, research has yet to be done on the municipal utility sector, one of the pillars of the energy transition. Although the potential synergies between decarbonization and digitalisation for sustainable transformation are widely recognised, limited research has been conducted to examine their integration within organizational frameworks [13,1,14].

The CO2 emissions associated with digital technologies are the subject of scientific research and have become increasingly important in view of their growing influence on modern society. Despite the widespread assumption that digital technologies have a comparatively low environmental footprint, it is crucial to understand their actual contribution to anthropogenic CO2 emissions. In addition to the production of digital devices, such as computers or sensors, there are other variables that increase the complexity of the carbon footprint [15]. Nevertheless, it must be recognised that digital technologies can also help to reduce carbon emissions in other sectors by enabling efficiency gains and replacing traditional processes with more environmentally friendly alternatives [11,3].

Existing literature, like the study on which our maturity assessment is based on, predominantly focuses on digitalisation efforts [16–18,14,12]. Furthermore, although some studies explore the feasibility of digitalisation or decarbonization efforts in various sectors, there is a lack of comprehensive research that examines the combined implications of integrating these two imperatives within municipal utility contexts.

In general, the current literature lacks a holistic evaluation of the integrated approach to decarbonization and digitalisation. Most studies acknowledge the potential benefits of decarbonization and digitalisation without providing a thorough analysis of their combined implications [5,19]. Additionally, surveys focusing specifically on these efforts often emphasize benefits while neglecting to address broader organizational integration aspects comprehensively [20]. Table 1 shows an overview of the research gap.

Table 1: Overview of the research gap

Survey	Zeller et al. [12]	Colli et al. [17]	Zoubek et al. [19]	Stock et al. [1]	Otoki et al. [5]	Isensee et al. [13]	Gökalp & Martinez [18]	Cinar et al. [16]	Trahan & Hess [1	Hasselmann [21]	Doleski, Kaiser et al. [11]	Ye [3]
Year	2018	2019	2021	2018	2023	2020	2021	2021	2021	2020	2022	2021
Municipal utilities	○	○	○	○	○	○	○	○	●	●	○	○
Digitalization	●	●	◑	◑	◑	◑	●	●	●	◑	●	●
Decarbonization	○	○	◑	◑	◑	◑	○	○	○	◑	●	●
Maturity Assessment	●	●	●	○	●	○	●	●	○	○	○	○

This research paper aims to fill this research gap by presenting a comprehensive analysis of the integrated approach to decarbonization and digitalisation within industrial and municipal utility contexts. This study aims to provide valuable insights for decision-makers and stakeholders in the industrial and municipal utility sectors by examining the synergies between decarbonization and digitalisation efforts and their implications for organizational transformation. The findings of this research will contribute to the development of strategies and frameworks tailored to the unique challenges and opportunities of integrating these two imperatives.

3.2 Results

3.2.1 Structural Areas

The structuring areas are based on the OSTO system model, a holistic management model that is used to shape and change organizations at a process or cultural level [21]. The structuring areas serve to cluster the capabilities to show the areas in which digitalisation and decarbonization must be shaped. A total of five structuring areas are shown.

In the following, the five design areas are introduced and described.

Development and Tasks: The first area, "Development and Tasks", describes all mechanisms and processes used for decision-making in municipal utilities. On the other hand, the area refers to objectives and functions that are to be performed, i.e. which tasks a municipal utility must fulfil. The design of this component aims to create efficiency and transparency.

Information systems: The second area, "Information systems", relates to the collection, processing, storage, and provision of information in municipal utilities. Information systems are used to transform data into useful information that can be used by the users of the system to fulfil their tasks and make decisions. The design of information systems should aim to make information accessible, understandable, accurate and reliable. This includes aspects such as data modelling, information architecture, user interfaces and data protection.

People: The "People" Design area summarises all components that have to do with individual employees, groups, or the utility. It encompasses a variety of aspects, including capabilities and competencies as well as cultural aspects, to drive digitalisation and decarbonization efforts.

Organisation: The fourth Design area is "Organisation". This component refers to the structure, processes, and relationships within municipal utilities. Organizational factors such as hierarchies, communication channels and decision-making processes have a significant influence on the implementation and use of new technologies or structures.

Technology: The fifth and final Design area "Technology" relates to technological elements, including hardware, software, interfaces, and infrastructure. The selection, development and implementation of suitable technologies require an in-depth understanding of the requirements as well as the technical possibilities and limitations.

3.2.2 Capabilities within the maturity model

The collected capabilities and their allocation to the Design areas are presented below, where they are categorized based on their contribution to decarbonization or digitalisation efforts, or as superordinated capabilities.

Development and Tasks: The first group refers to the design area "Development & Tasks". Table 2 shows an overview of the capabilities.

From a decarbonization perspective, five capabilities are relevant for this area. The energy consulting capability describes advisory services for consumers regarding the ongoing energy transition and general sustainability issues. The funding management capability comprises the identification of available funding pots and the successful acquisition of funding to finance projects or initiatives. Cross-sector project development capability includes the planning and implementation of projects that span multiple sectors such as electricity, mobility, heat, and gas, as well as collaboration across departmental boundaries to achieve a holistic and integrated solution. Municipal networking capability involves the strategic use of relationships with other municipal institutions, authorities, and organizations to create synergies, share resources, exchange information, and drive forward joint projects or initiatives. This may include working with local government agencies, educational institutions, non-profit organizations, businesses, and other relevant stakeholders to increase the efficiency and effectiveness of municipal utility activities and better meet the needs of the community. The risk management capability comprises the systematic identification, assessment, and management of risks to respond appropriately to uncertain and dynamically changing conditions and to ensure that the municipal utility achieves its objectives. Two capabilities are relevant for digitalisation projects. Digitalisation management involves developing and implementing strategies to drive forward the digital transformation in various areas of the company. This includes the integration of digital technologies, processes, and innovations to increase efficiency and improve competitiveness. Information security is ensured through comprehensive measures, including the implementation of security guidelines, regular audits, and training as well as the use of modern security technologies.

Table 2: Capabilities from the area “Development & Tasks”

Design Area	Decarbonization	Digitalisation	Superordinate
Development and Tasks	Energy consulting service	Digitalisation management	Change management
	Funding management	Information Security	Innovation management
	Cross-sector projects		Capacity management
	Municipal networking		Capabilities management
	Riskmanagement		Customer management
			Project management
			Process management

The area of superordinate capabilities includes various management capabilities. Change management involves the initiation of change processes through clear communication, stakeholder involvement and the provision of resources. These processes are continuously monitored, evaluated, and adjusted to ensure that the objectives of the change are achieved, and that the organization continues to develop successfully. In capacity management, personnel capacities are monitored by regularly analysing workloads and employee capacities. Adjustments are made through flexible working time models, training, and targeted resource allocation to ensure that the labour force effectively meets changing requirements. The competence management capability involves the targeted training and development of employees through individual development plans, training and mentoring to ensure that they have the necessary capabilities and knowledge to successfully fulfil their tasks. The customer management capability deals with the extent to which customer relationships are maintained and customer satisfaction is recorded and optimised. The focus here is on standardised processes for customer management, the use of customer relationship management systems or the integration of social media. Regarding project management capabilities, the question is asked whether traditional project management approaches or agile methods are used.

Information systems: The second group describes capabilities for digitalisation from the area of information systems. No capabilities for Decarbonization or higher-level aspects are relevant in this area. Table 3 provides an overview.

Table 3: Capabilities from the area “Information systems”

Design Area	Decarbonization	Digitalisation	Superordinate
Information systems		Data analysis	
		Data volume	
		Horizontal integration	
		Provision of information	
		IT-Resilience	
		IT-System transparency	
		Vertical integration	

The data analysis capability deals with data-based decision-making in utilities. Statistical analysis methods and digital technologies play a role here, e.g. to analyse real-time data to take precise and effective measures. The capability in data volume includes the implementation of robust data backup systems and scalable data management solutions to ensure that relevant data can be efficiently backed up, managed, and made available for the present and future. Horizontal integration capability manifests itself in the effective use of standardised interfaces and protocols to enable data exchange with external partners and systems, ensuring seamless collaboration across organizational boundaries. As part of the ability to provide information, information on energy consumption data is provided using interoperable systems and standardised data formats that enable efficient exchange with external partners to promote transparency and collaboration about energy consumption data. IT resilience capability includes implementing robust backup and recovery solutions, regularly reviewing, and updating security measures and setting up redundant systems to ensure the stability of IT systems and minimise downtime. The capability for IT system transparency includes the provision of clear documentation, training, and support mechanisms to ensure that employees have a comprehensive understanding of how the IT systems work and can use them transparently and effectively.

In addition, regular communication channels and feedback mechanisms are provided to answer questions and resolve any ambiguities. Vertical integration capabilities include the implementation of data integration solutions and communication mechanisms to ensure the seamless exchange of relevant data and information between different departments and levels. This enables efficient collaboration and decision-making across all hierarchical levels.

People: The third group of capabilities relates to the area of “People”. In total, two skills each are relevant for digitalisation and overarching aspects and one skill for Decarbonization. The following Table 4 shows a summary.

The sustainability competence capability is concerned with the average competence of the workforce in sustainability. This is about employees' understanding of general sustainability issues and the impact of their behaviour on the environment. The digitalisation competence capability involves the ongoing assessment of employees' skills in the effective use and application of digital technologies. This also includes understanding how to use digital technologies for innovation development and process optimisation. As an overarching capability that shapes the entire organization, effective innovation management is crucial to continuously generate, evaluate, and implement new ideas, thereby ensuring that the municipal utility remains competitive in the long term.

Table 4: Capabilities from the area “People”

Design Area	Decarbonization	Digitalisation	Superordinate
People	Sustainability competence	Digitalisation competence	Communication culture
		Internal communication culture	Reflection/ error cultur

The innovation management capability establishes mechanisms that enable employees to contribute ideas, provide feedback and actively participate in innovation projects, fostering a culture of experimentation and learning and encouraging employees to think creatively and develop innovative solutions. The "error culture" capability encompasses an open and transparent approach to errors within the municipal utility, in which employees are encouraged to view errors as a learning opportunity and communicate them openly. Management supports this process by providing supportive measures and learning opportunities to learn from mistakes and continuously drive improvements.

Organisation: The fourth area, "Organisation", looks at collaboration skills. The following table 5 shows one capability that contributes to Decarbonization, while two are relevant for digitalisation and five for overarching aspects.

The Business Sustainability Alignment capability involves close collaboration between the specialist departments and the sustainability think tank, with the topic of sustainability being actively promoted to integrate sustainable practices into business processes. The Business-IT Alignment capability involves effective collaboration between the specialist departments and IT, with IT acting as a strategic partner to support business objectives and provide innovative solutions. The "Data Strategy & Data Governance" capability involves defining clear guidelines and processes for handling data and ensuring its quality. This is done by defining data standards, implementing data collection and management procedures, and setting up monitoring mechanisms to ensure data integrity and security. The "Incentive system" capability includes the design of incentive structures that promote and reward employee performance and commitment. This includes the development of transparent and fair incentive programmes based on clear targets and performance criteria, as well as the regular review and adjustment of these systems to ensure continuous motivation and target achievement.

Table 5: Capabilities from the area “Organisation”

Design Area	Decarbonization	Digitalisation	Superordinate
Organisation	Business Sustainability Alignment	Business IT Alignment	Incentive system
		Data Governance & Data strategy	Power of decision & responsibility
			Interdisciplinary collaboration
			Collaboration with partners
			Target systems

The "decision-making authority and responsibility" capability involves defining clear responsibilities and authorities for employees in decision-making processes. This enables employees to make appropriately informed decisions while taking responsibility for the outcomes of their decisions and contributing to the achievement of organizational goals. About the ability to collaborate internally, clear rules and process standards are established to guide and improve collaboration between departments. This enables efficient interaction in which information and resources can be exchanged effectively to achieve common goals and utilise synergies. As part of the ability to collaborate with supra-regional partners, there is a continuous exchange and cooperation with other organizations such as municipal utilities, associations, thematic networks, and science. These partnerships serve to share information and resources, tackle common challenges and develop innovative solutions to strengthen the municipal utility's performance and improve its competitiveness. The "target system" capability involves designing clear and measurable target systems for employees. This involves defining individual objectives that are in line with the overarching corporate objectives to enable effective performance management and monitoring and to promote employee motivation and commitment.

Technology: The skills assigned to the area of technology are summarised in Table 6.

Table 6: Capabilities from the area “Technology”

Design Area	Decarbonization	Digitalisation	Superordinate
Technology	Providing sustainable enegry	System interfaces	
	Dynamic load management		

The "Providing sustainable energy" capability deals with the provision of electricity, gas, and heat in a sustainable manner, for example from renewable energy sources. The dynamic load management capability includes active support in the provision of flexibility for the overarching energy system. This is made possible by the implementation of intelligent control and regulation systems that allow the municipal utility to flexibly adjust loads and thus react to fluctuations in the grid to improve the stability and efficiency of the overall system.

The capability of energy system interfaces is to effectively utilise sensor technology and sensor data to improve process control and efficiency. This is made possible by integrating advanced sensors and data analytics technologies into the plant interfaces to capture and use real-time information to optimise processes, maximise performance and minimise costs.

4. Conclusion and Outlook

The preceding research presents a comprehensive investigation into the integration of decarbonization and digitalisation within industrial and municipal sectors. It underscores the current imperative for organizations across various industries to reassess their strategies in addressing climate change and to devise measures fostering sustainability. Particularly emphasized is the close nexus between digitalisation and decarbonization, alongside the challenges associated with integrating these two domains. The core findings of the inquiry encompass the identification of Design areas and capabilities propelling digitalisation and decarbonization within municipal utility companies. Herein, the acatech Industry 4.0 Maturity Index serves as a foundational framework, adapted to incorporate the significance of decarbonization. Various Design areas such as Development and Tasks, Information Systems, People, Organization, and Technology were identified and scrutinized. Additionally, capabilities requisite for the successful implementation of digitalisation and decarbonization strategies were examined and categorized. The study also underscores the research gap prevalent in comprehensively evaluating the integrated approach to decarbonization and digitalisation, stressing the need for further inquiry in this domain.

The present study provides the basis for a skill-based maturity model that has been supplemented with aspects of decarbonization. In the project Roadmap.SW, based on this work, maturity levels for each skill are now determined and integrated into an assessment tool, which advances municipal utilities in determining their maturity levels for decarbonization and digitization. From this, various measures can be derived to close the gap between the current status quo and the desired goals. In the future, a transfer to other industries is conceivable. However, this requires the adaptation of skills that are currently heavily focused on energy generation and distribution. Here, a stronger focus on production would be necessary. Basic skills and the framework with the design areas can be adopted from this research. In addition, further research is needed that delves deeper into the dependencies between decarbonization and digitization skills. The present study also provides an initial basis for this, upon which further development can be built.

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Biography

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