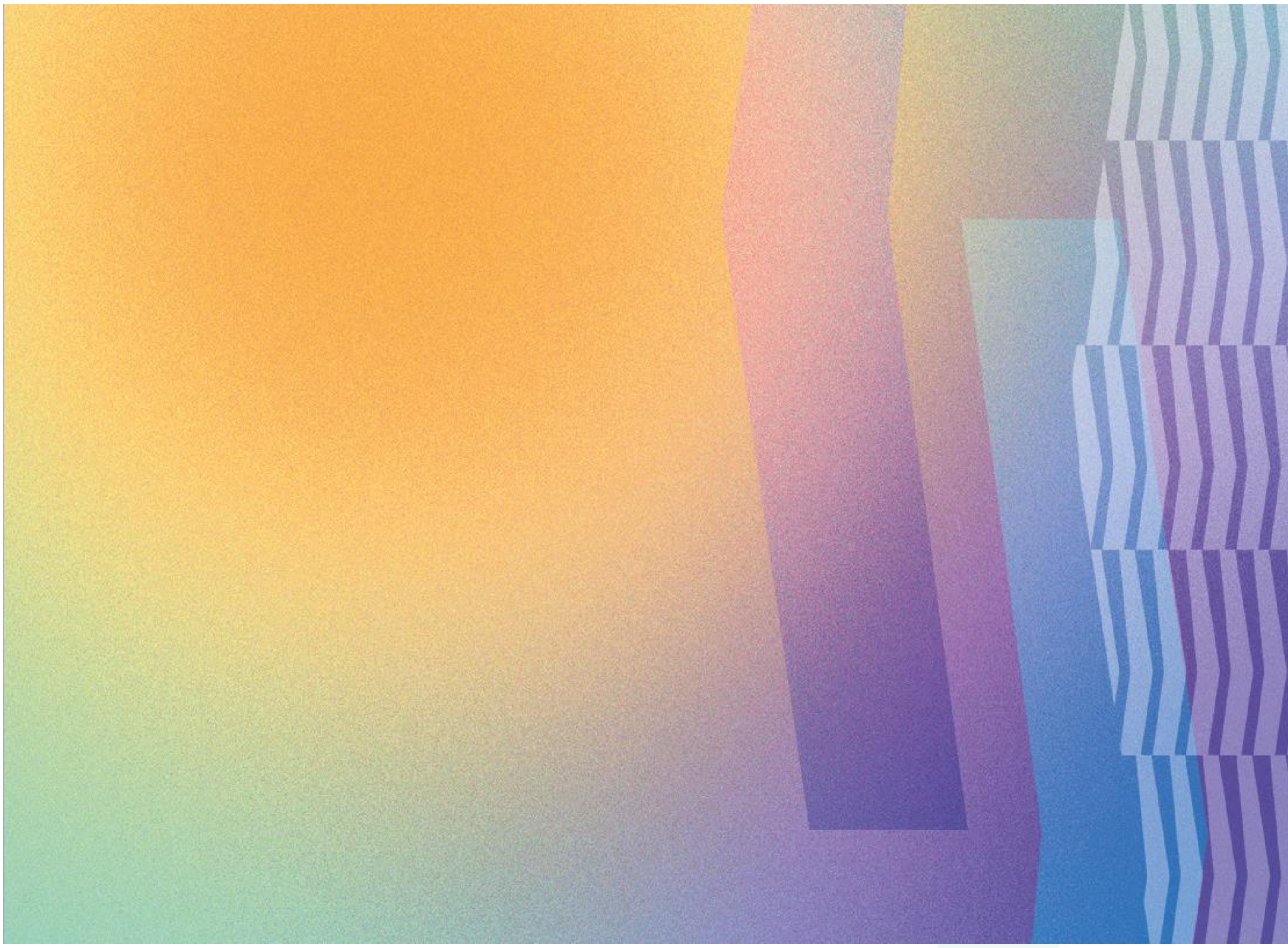
EDGE
Datenwirtschaft

Technology Program Edge Data Econonmy
German Federal Ministry for Economic Affairs and Climate Action



EDGE COMPUTING IN THE DATA ECONOMY

Opportunities, Challenges and Recommendations for Action

Imprint

This study was commissioned by the
German Federal Ministry for Economic Affairs and Climate Action
as part of the coordination and support action (Begleitforschung)
for the technology program Edge Data Economy (Edge Datenwirtschaft)

Author

Nils Jahnke

Fraunhofer Institute for Software and Systems Engineering ISST
Dortmund

Editors

Peter Gabriel
Dr Nicole Wittenbrink

Begleitforschung Edge Datenwirtschaft
Institute for Innovation and Technology (iit)
within the VDI / VDE Innovation + Technik GmbH
Berlin

Date

September 2024

Layout

LHLK Agentur für Kommunikation

Contents

1 Introduction

As data volumes continue to grow, data is increasingly viewed as an economic asset. Organizations derive value from data when it is transformed, aggregated, and turned into actionable information through analytical processes. Used in this way, data becomes the foundation for operational excellence, strategic decision-making, and innovation in the form of enhanced value propositions or novel business models. The ability to manage data along the data value chain to maximize its value is becoming a key competitive factor and increasingly a prerequisite for business success.

Several factors currently limit the ability to fully realize the business potential of data: for example, companies must first build powerful data infrastructures to capture, process, and analyze data of sufficient quality and in a timely manner. Further, they must comply with the local data protection and data security regulations during data processing. In addition, companies fear the loss of trade secrets when sharing data with third parties and are thus reluctant to transfer data across organizational boundaries.

Edge computing can overcome these obstacles by processing and analyzing data in physical proximity to its point of origin. Integrating computing power into user devices, machines and systems, buildings, or existing telecommunication infrastructure ensures lower data processing latencies. The use of edge computing makes it easier to comply with data processing regulations and to collaborate with third parties while maintaining data sovereignty, as raw data is analysed on the data holder’s premises. In addition, the use of edge computing can reduce energy consumption and increase user satisfaction.

As edge computing is a relatively new concept, there is currently a lack of awareness and understanding of edge computing in general, as well as the profitable use of edge computing in potential application scenarios. As a result, the attributed economic potential has yet to be fully realized. In particular, less digitalized small and medium-sized enterprises (SMEs) struggle to define promising value propositions based on edge computing (techUK, 2021).

To target the prevalent status, this study provides guidance for organizations, especially SMEs, regarding the use of edge computing. It is aimed at executives and business development professionals who are interested in designing novel, data-driven process improvements or innovations. In particular, the study addresses the following questions:

- What defines the "data economy" and what are the characteristics of edge computing?
- Which technical, organizational, economic, and legal factors motivate companies to use edge computing in novel products, services, and business models, and what challenges arise during edge computing implementation?
- What are particularly important aspects when developing and evaluating edge computing products, services, or business models?

The study was conducted in context of the coordination and support action (Begleitforschung) for the technology program Edge Data Economy of the Federal Ministry for Economic Affairs and Climate Action (BMWK). In this program, ten projects develop innovative digital technologies for the data economy in the edge-cloud continuum[1]. The results presented in this study are based on the analysis of edge computing use cases that are being designed and implemented in the funded projects at the time of publication (see Figure 1). The project participants are primarily early adopters of edge computing. To identify and assess the motivations and challenges in developing and deploying novel edge computing use cases, a survey of project participants was conducted in August and September 2023. About 40 participants answered this survey.

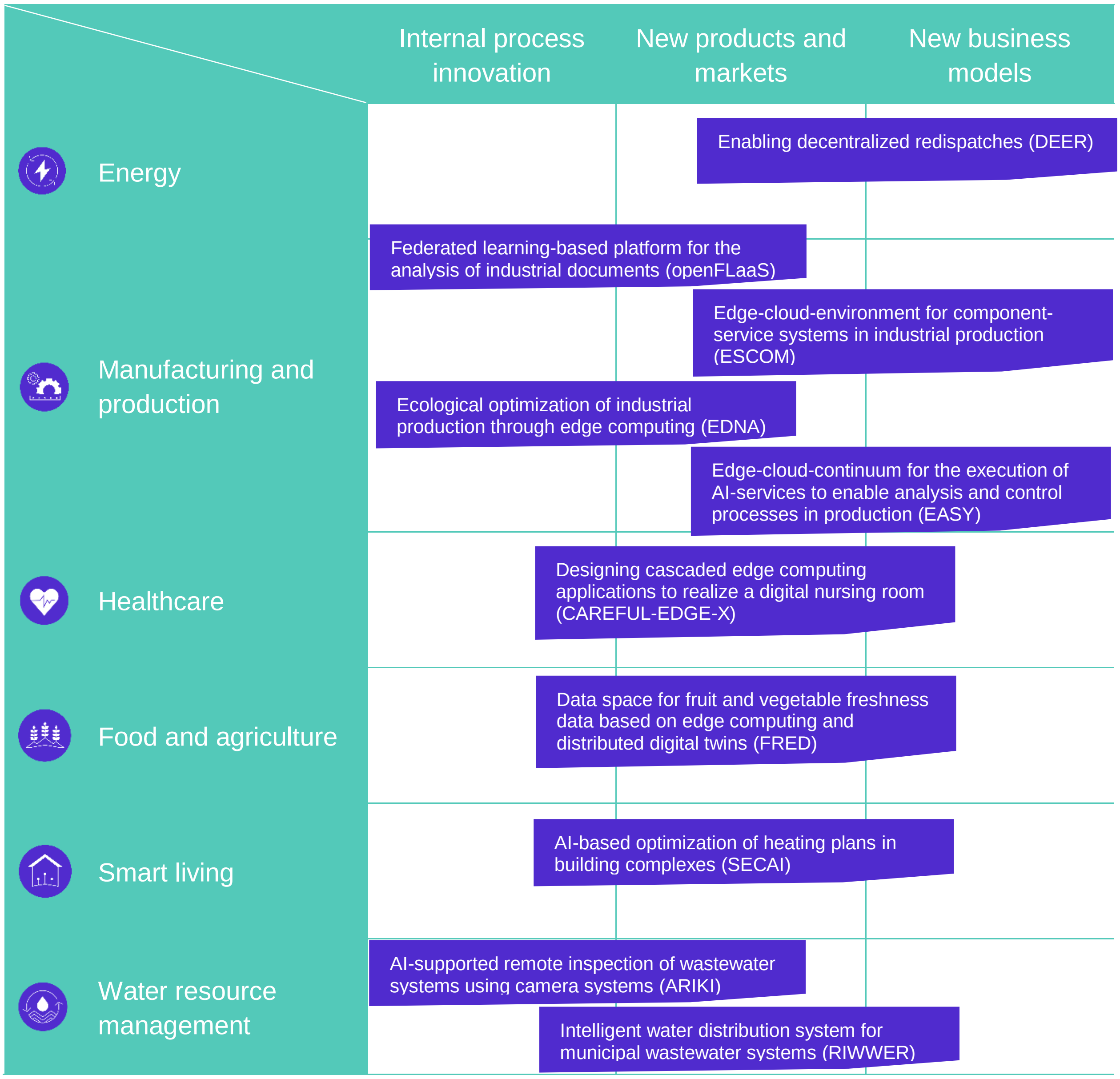


Figure 1. Use cases in the technology program Edge Data Economy

[1] Further information on the technology program Edge Data Economy can be found at https://www.digitale-technologien.de/DT/Navigation/EN/ProgrammeProjekte/AktuelleTechnologieprogramme/Edge_Datenwirtschaft/edge_dw.html.

2 Foundations

The data economy and edge computing are relatively new concepts that are still vaguely defined. Therefore, we will shortly introduce both concepts in this section.

2.1 Data Economy

Data is increasingly viewed as an economic resource. Like labor and capital, it is an important input factor to achieve business objectives. Data can be used to connect and automate business processes or to improve decision-making. Data is also crucial for optimizing existing business models and developing innovative services. A typical example is the "everything-as-a-service" approach, where data provides the basis for usage-based billing and enables new value-added services such as predictive maintenance or condition monitoring. Ultimately, data itself can become a product that is traded through data marketplaces or data brokers.

This development is captured by the term “data economy”, in which data represents the central resource. The difference in value creation in the data economy compared to the traditional economy is primarily based on the unique properties of data compared to other economic resources. Data only becomes valuable when it is combined with other data in the context of analytics and transformed into actionable information. Thus, data is often considered an experience good whose value can only be assessed after its use. Moreover, data can be replicated and shared at low marginal cost.

At present, the term "data economy" does not have a universally accepted definition. The core idea of the data economy is that data and algorithms are used within economic activities to drive new business models or to replace existing ones. Revenues from these models can be generated both internally and externally. Internal revenues are generated when the surplus of information is leveraged for efficiency gains or provides a competitive advantage, while in external revenue models the information is sold or provided as part of product or service offerings.

The emerging data economy promises innovation and efficiency improvements for many established industries (Curry et al., 2021). In addition to financial gains, the information generated in the data economy can also lead to social and environmental benefits. To produce the associated benefits, appropriate data value-creation processes must be implemented (see Figure 2). The first step is to collect raw data through automated measurements or manual input. Often, the raw data cannot be processed directly, so initial data preparation processes such as data cleansing or data transformation must take place. The central process of the data economy is the integration of data into analytic models to derive actionable insights. The resulting information must then be made available to users through appropriate interfaces. Ultimately, humans and machines use information to guide their behavior.

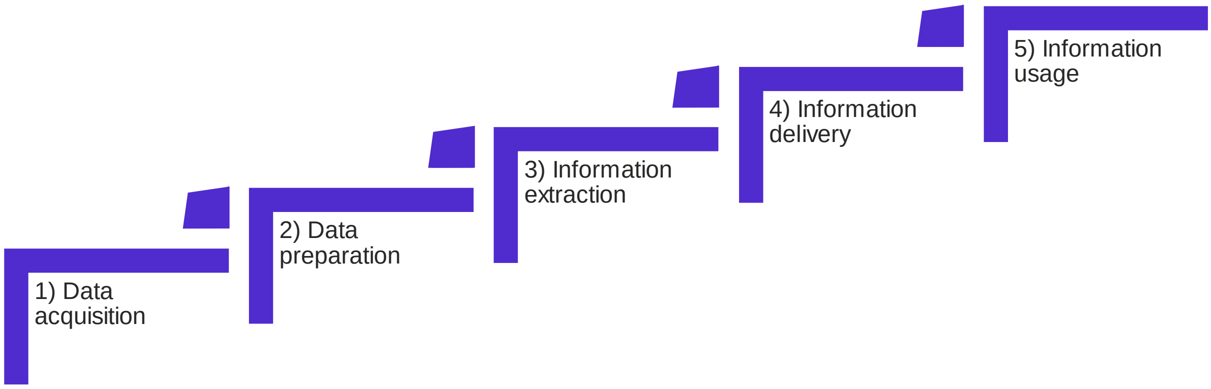


Figure 2. The value chain in the data economy according to Bundesverband Digitale Wirtschaft (BVDW) e.V. (2018)

Various digital technologies are used along the data value chain to extract value from data. This includes cloud technologies, which have long been used to store, process and analyze data. Hyperscalers such as Amazon Web Services, Google Cloud Platform, and Microsoft Azure, which account for approximately two-thirds of the global cloud market, are the main beneficiaries. The hyperscalers' market power is based on three core capabilities: a) computing and storage infrastructure combined with data services, b) business services and consulting, and c) a broad customer base (Demchenko et al., 2018). Successful platforms such as Uber or Facebook benefit from analyzing the immense amounts of data created and provided by platform participants. These companies capitalize on the fact that value flows in the data economy are not bidirectional but are instead concentrated in a network structure with the platform at its core. The party that benefits from a service is no longer necessarily the one that pays for it (Curry et al., 2021). For example, Google Maps is free for individuals because the service is funded by advertising revenue from businesses.

Challenges in the data economy

Studies show that in 2022, only around a third of German companies in industry and industry-related services were able to manage data efficiently (Büchel & Engels, 2022). Small and medium-sized enterprises (SMEs), in particular, are finding it difficult to participate in the data economy. The causes are manifold, including economic, organizational, technical, and legal challenges.

A lack of data culture and employee resistance often hinder the development and adoption of new data-driven solutions. From a legal perspective, many companies are unclear about data protection requirements. Additionally, there are concerns about the ability to technically ensure the necessary data protection and security.

The ever-increasing volume of data along the data value chain requires adequate data management. Designing and implementing powerful architectures is crucial for managing, storing, and processing large amounts of data. The development and implementation of data-based solutions, along with the preparation needed to build up a sufficient collection of high-quality data, initially require significant efforts. Adoption, usage, and revenue depend on the level of digitization of potential customers, and companies can therefore find it difficult to assess the profitability of data-based products and services in advance. As a result, companies often refrain from developing and implementing novel data-driven solutions.

In the business-to-business sector, it is particularly challenging for a single organization to collect all the necessary data for an innovation. Often, data is needed from multiple sources and across domains. Thus, sharing data across organizational boundaries is important for the successful development of digital business models. However, data sharing comes with the fear of losing control of one's data when it is transferred to a business partner and the fear of revealing a company’s trade secrets. Accordingly, establishing technical or organizational mechanisms to create data sovereignty, i.e., the ability to control the use of data even after it has been transferred, is a key challenge in the data economy.

2.2 Edge Computing

To realize the economic potential of data, companies are deploying a range of technologies along the data value chain to extract, process, and deliver data and, consequently, information. One increasingly relevant technology is edge computing. The use of edge computing is often aimed at solving the problems of the data economy described in Section 2.1.

The initial strategic impetus for edge computing arises from the limitations of the current Internet infrastructure. The proliferation of intelligent devices and sensors, especially in sectors such as industrial manufacturing or water and energy management, generates ever-increasing volumes of data and requires real-time decision-making capabilities. However, the existing internet infrastructure operates on a best-effort basis. Individual data transfers can take up to several hundred milliseconds and therefore cannot support innovative use cases with real-time demands (Linux Foundation, 2022). In addition to these technology-driven incentives, there is a reluctance, particularly in Europe, to transfer data to centralized cloud services operated by non-European hyperscalers, largely due to data privacy concerns.

The application focus of digital technologies is shifting from enhancing efficiency, effectiveness, and speed to addressing tasks in a completely novel manner. Here, edge computing plays a crucial role by supporting the growing demands for regionalization and the move away from centralized infrastructures (Marcham, 2021). Edge computing can support both domain-specific and domain-agnostic use cases.

The concept of edge computing and its practical realization

Edge computing is generally understood as the provision of computing power and storage near the boundary (edge) between the physical and digital world (Linux Foundation, 2022). The edge consists primarily of sensors and actuators that make signals and states from the physical world accessible to the digital world or translate instructions from the digital world into physical actions. In a hierarchical arrangement of various computing systems, edge computing places computing power and storage close to where the data is generated to reduce the amount of data that needs to be sent to the cloud or other centralized systems. As a result, it enables low-latency computing. The specific structure of the edge can vary from system to system. In extreme cases, computing and storage can be provided directly on the sensors and actuators. In other cases, edge computing power is separate from the devices, but placed in close physical proximity. Simply put, edge computing encompasses all computing and networking resources between the data source and the cloud data center (Jain & Mohapatra, 2019). In addition, edge computing is a distributed system as power and storage are distributed across different nodes.

There are different perspectives on the specific scope of edge computing. From the Linux Foundation's perspective, edge computing focuses on computing and storage elements in the “last mile” of the network, while the European Commission uses a broader definition of edge computing that also includes more distant data centers outside of hyperscaler infrastructures.

A variety of options for implementing edge computing along the edge-cloud continuum exist, which can be used in isolation or in combination. The decision to place computing and storage at specific points along the continuum depends on the use case requirements and boundary conditions. Like cloud computing, edge computing services can be delivered in various ways, including private, public, community, or hybrid deployments. Figure 3 shows the typology of edge computing according to 3DS Outscale et al. (2021):

- On-Device Edge: Deployment of an edge unit directly in the object of interest, such as a vehicle or a device with sensors, actuators, or a user interface.
- On-Premises Edge: Local deployment of computing power for an environment, such as a factory or an office building.
- Far Edge: Coverage of specific zones with high demands for computing power, bandwidth, and latency, such as shopping centers or business parks.
- Near Edge: Provisioning of infrastructure services between the far edge and the data centers of cloud service providers, for example, at the nodes of telecommunications providers.

The use of cloud and edge resources is orchestrated according to the application requirements. (Public) cloud services are particularly scalable and elastic. Therefore, they are used in edge-cloud scenarios to store and process large volumes of data from multiple sources and for orchestration purposes. The edge, on the other hand, is used for subtasks that require real-time data processing and resiliency. Typically, in such a hierarchical system, greater centralization also means greater ability to aggregate data from internal and external sources.

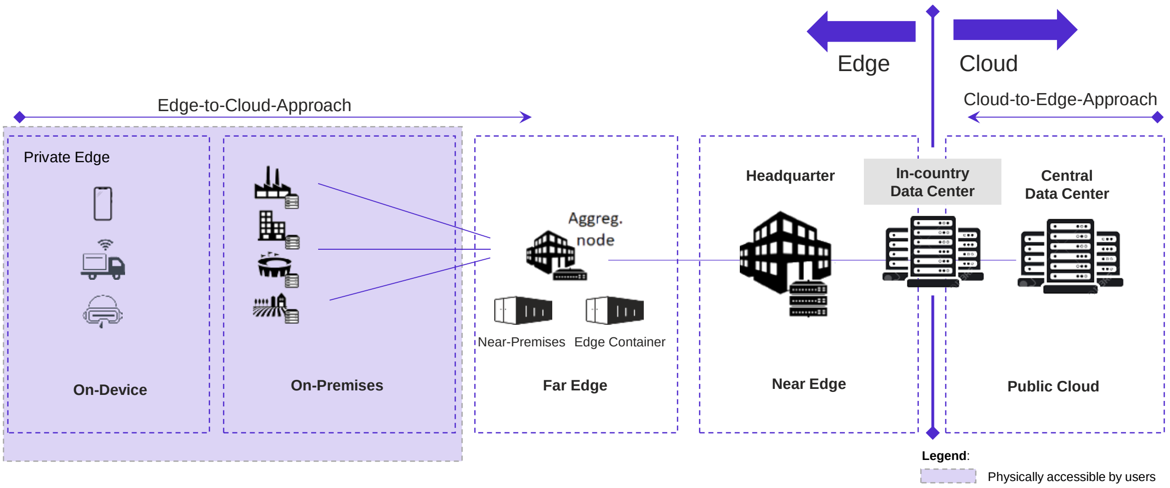


Figure 3. Edge-cloud-continuum based on 3DS Outscale et al. (2021)

The use of edge computing along the data value chain

Creating value in the data economy requires the use of various technologies throughtout the data value chain. As one of these technologies, edge computing can be used to support various processes (see Figure 4).

In the first step (data acquisition), edge computing – particularly the device edge – supports the gathering of data from objects and processes due its ability to reliably collect vast amounts of data. Virtual sensors can also be implemented on the device edge to calculate further variables from available sensor data (e.g., image data) that are usually difficult to measure.

As part of the data preparation step, applications running on edge devices can evaluate the data, such as assessing its usefulness or privacy relevance. If personal data has been identified, the data can be anonymized or pseudonymized locally on the edge devices, before their transmission and further processing. In addition, additional data preparation aspects such as data cleansing, data transformation, or data normalization are also possible.

In the information acquisition phase, edge computing enables use cases that require real-time processing of large amounts of data. Due to the limited computing resources of edge devices, specially designed analytics and AI models (edge analytics / edge AI) are employed for this purpose.

The information obtained from the analyses at the edge can subsequently be made available to initiate state changes in intelligent devices, perform further analyses, or be stored long-term by cloud services. Conversely, information from the cloud can be used by edge computing devices. This is the case, for example, when a machine learning model is trained in the cloud and distributed as a lightweight model to an edge device, which then uses this model to generate new insights.

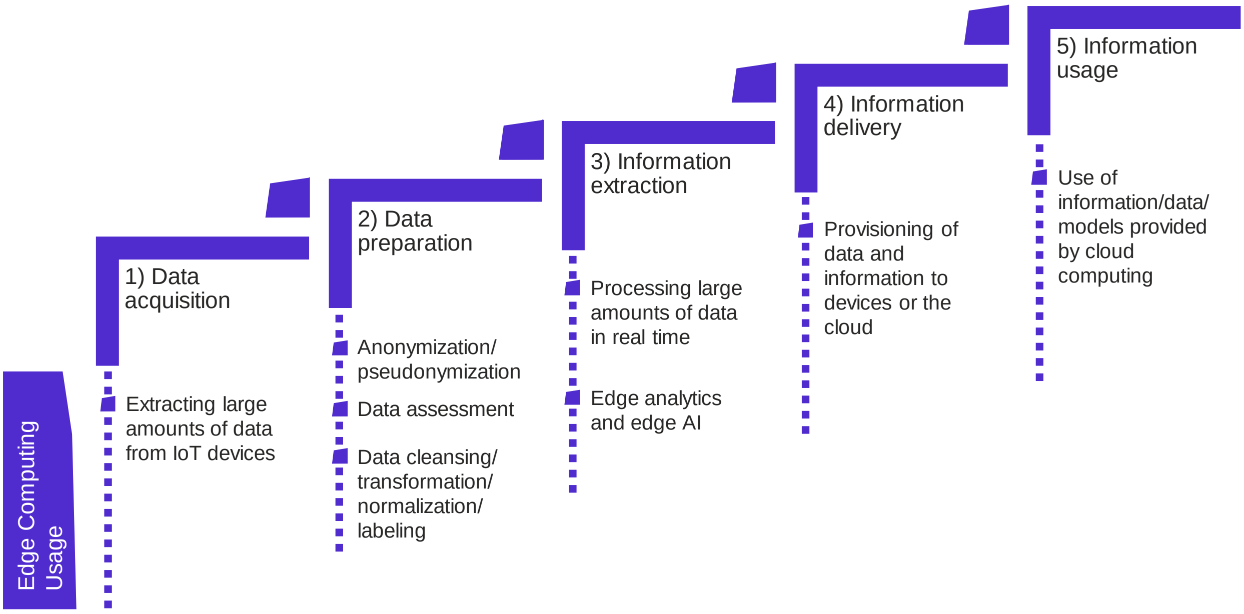


Figure 4. Possible applications of edge computing in the data value chain

2.3 The Relevance of Edge Computing for the Data Economy

The high complexity of data value creation presents many challenges for companies, which can be addressed by using edge computing (see Figure 4).

Privacy and data security are enhanced by processing data at the edge. Sensitive data is processed locally, and only less sensitive data is transferred to partners or cloud environments. At the same time, enterprise data sovereignty is strengthened by keeping and processing large amounts of data locally and within the enterprise's control. This also helps to address the lack of trust in partners, as only less problematic data needs to be shared.

Another problem in the data economy is managing the ever-increasing amount of data. By using edge computing, data can be pre-processed locally to reduce the total amount of data that needs to be stored or managed. Edge computing also addresses the high cost of establishing a data estate in two ways: first, it reduces the dependency on cloud services, which may be expensive in the long term, particularly when large amounts of data need to be transferred between the cloud and local systems. Second, it lowers the energy costs associated with data transmission.

At the same time, providing a powerful and sustainable infrastructure for data processing is necessary. Edge computing supports this by reducing latencies in data processing and allowing higher bandwidths to the location of data analysis. Similarly, edge computing improves the resilience of the infrastructure against connectivity failures.

In addition to the potentials of edge computing for the data economy, there are some overlapping challenges that organizations need to address. These include estimating the return on investment of edge computing applications or addressing acceptance issues among employees when implementing novel solutions.

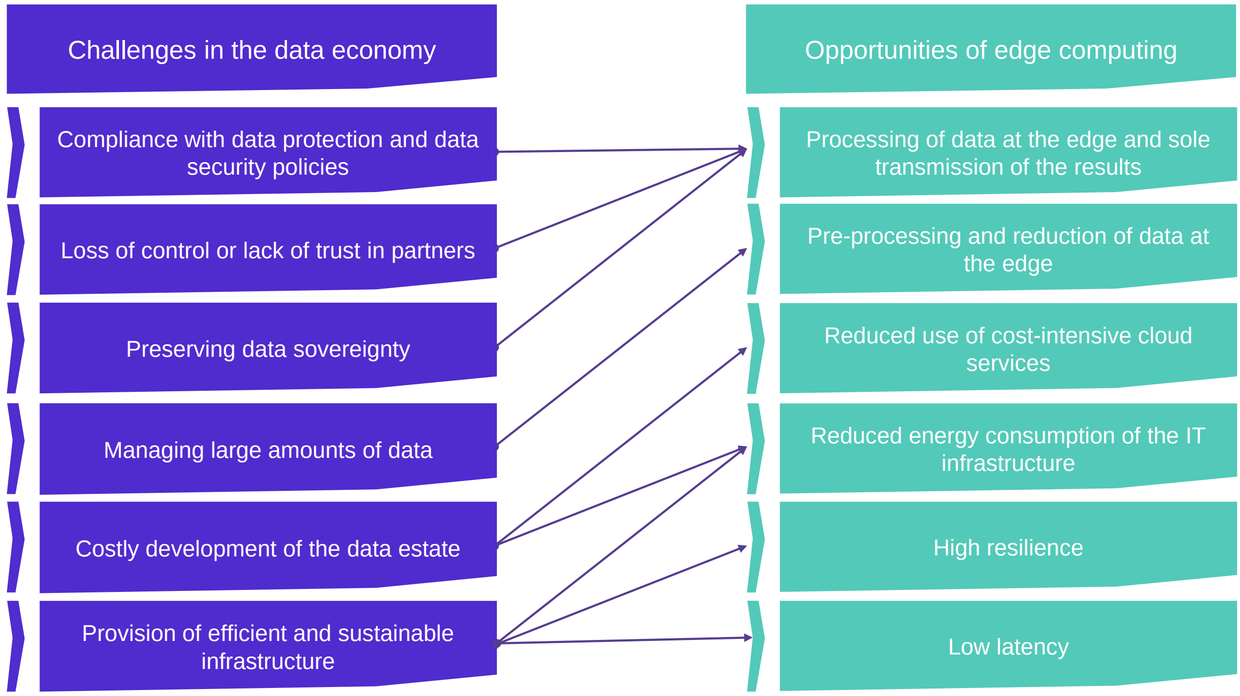


Figure 5. The relevance of edge computing for the data economy

3 Opportunities and Challenges of Edge Computing in Practice

The deployment of edge applications in practice is driven and supported by a number of potential benefits. At the same time, it is impeded by unique challenges attributed to the current state of the art in edge computing. This section describes both the opportunities and challenges associated with deploying edge computing applications from the perspective of early adopters who are currently engaged in pioneering edge computing initiatives (see Figure 6). This comprehensive overview helps decision makers and practitioners in organizations considering the adoption of edge computing. In addition, it provides insight into potential obstacles they may encounter while implementing their own edge computing application(s). The results are based on an online survey conducted in August and September 2023 among the participants of the technology program Edge Data Economy, which is funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK).

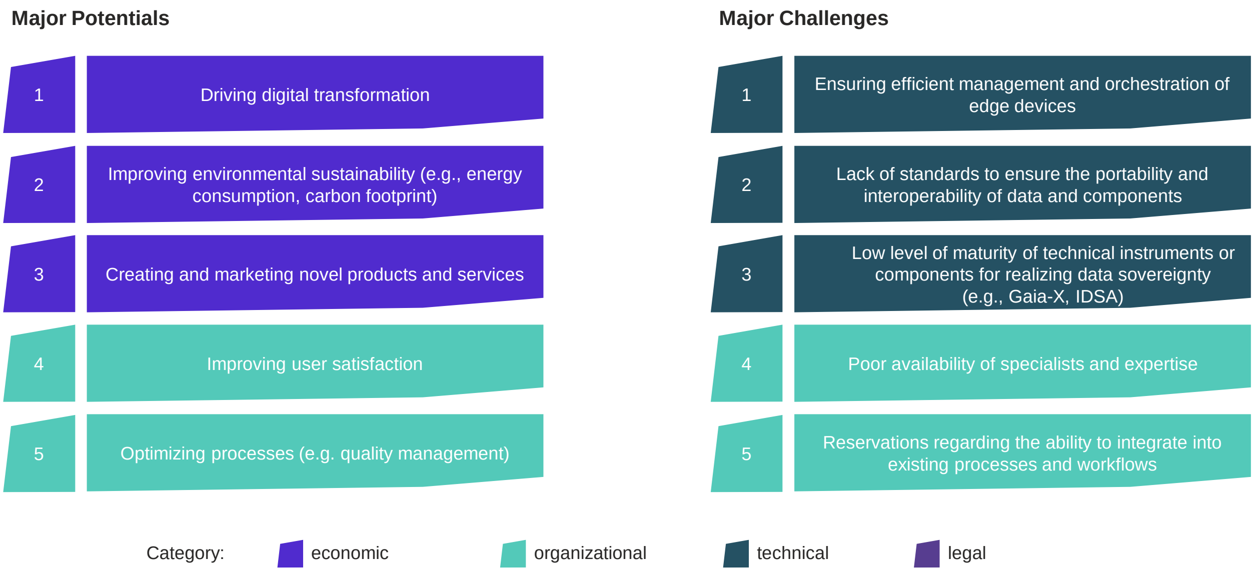


Figure 6. Early adopters' key opportunities and challenges of edge computing

3.1 Opportunities

Early adopters generally view economic factors as the highest potential benefits of edge computing adoption. Overall, respondents rate driving digital transformation, improving environmental sustainability, creating and marketing innovative products and services, improving user satisfaction, and optimizing process workflows as the strongest potential benefits of edge computing implementations. These drivers are described below.

Driving digital transformation

Early adopters have identified driving digital transformation as the greatest potential benefit of using edge computing. The term digital transformation generally refers to the active and disruptive change in the economy and society brought about by using digital technologies. Edge computing, as one of these technologies, can support digital transformation for user organizations in various ways. Edge computing applications can change the structure of service delivery and value creation. By using edge computing, internal processes can be improved or made more cost-effective, for example, by digitizing previously analog processes. It can also transform a company's products, services, and revenue models. A typical example is the various servitization models enabled by edge computing. Finally, digital transformation can also change the way a company interacts with its customers. For example, edge computing applications enable novel, data-driven interactions between product manufacturers and product consumers.

Improving environmental sustainability

The potential to using edge computing to improve the environmental sustainability of applications was rated as the second most important by the respondents. Edge computing enables the implementation of applications that lead to a reduction in energy consumption. This includes, for example, the intelligent control of systems relying on fossil fuels (e.g. heating systems)[2]. Furthermore, the intelligent distribution of data using edge computing can reduce the consumption of primary energy in IT architectures by up to 20% compared to cloud-centric scenarios (European Commission, 2023). These energy savings are mainly achieved by reducing computing and network load through decreased data transmission. For example, frequently accessed data is stored closer to the data consumer, while less critical or infrequently used data is stored in the cloud. Furthermore, some raw data can be deleted at the edge after it has been analysed. This also has economic benefits: Lower data transfer means lower data transmission cost, which is particularly relevant for telecommunication service providers, who must bear ever-increasing costs to ensure the agreed service levels are kept.

Creating and marketing novel products and services

The chance to develop and market novel products and services is considered a further decisive economic potential of edge computing by the sample of early adopters. Edge computing is mainly used for new products and services and less for the incremental improvement of existing processes. One prominent example for service offerings are subscription models, in which formerly capital-intensive investment goods such as production machines are made available through usage-based billing models. Edge computing ensures the continuous analysis of billing-relevant parameters. In addition, user companies can leverage edge computing applications as a foundation to develop new types of products and services themselves. The use of edge computing gives users access to the data they generate, which can be shared with their customers, for example, to increase transparency about products and processes and to document compliance with regulation.

Improving user satisfaction

Respondents identified the ability to improve user satisfaction as the greatest organizational (and non-economic) potential of edge computing. Given the ever-increasing demands of application users, delivering satisfactory application performance is a continuous challenge. Typical

[2] See project SECAI in Figure 1.

user demands for digital services include speed, continuity, personalization, integration, and, increasingly, privacy or, in the case of enterprises, protection of trade secrets. Edge computing applications can improve the user experience through local computing and integration with other key technologies. For example, local data processing through edge computing increases the speed of services and improves service quality by eliminating interruptions. Edge computing also enables the personalization of services while complying with data privacy regulations such as the General Data Protection Regulation (GDPR).

Optimizing processes

According to the surveyed early adopters, another important motivating factor for using edge computing is the potential to optimize existing process workflows. The ability to continuously improve core processes in a company's value chain is known as operational excellence. Several features of edge computing applications enable operational excellence: fast and reliable processing of data at the edge, combined with the use of artificial intelligence and IoT, can automate previously manual processes along the value chain. The use of edge computing enhances the real-time capabilities of control systems and enables decentralized control, for example, in industrial production or in the electricity sector.

Further insights: Data processing with unreliable connectivity and GDPR compliance seem less relevant drivers

The survey also revealed some surprising aspects. For example, early adopters rank data processing with unreliable connectivity, enabling context-aware services, and GDPR-compliant processing of personal data as the least important motivators for using edge computing. The first aspect contradicts previous publications from the hyperscaler environment, which identify data processing with unreliable connectivity as one of the main drivers of edge computing adoption (Noghabi et al., 2019). The provision of context- or location-aware services is also frequently named as core motivator of edge computing applications (Ahmed et al., 2017). However, there are currently only a few use cases in which devices share edge computing computing power flexibly in the so-called cyber foraging model. Current edge computing use cases are rather stationary and long-running scenarios. Hence, this edge computing potential is currently not being appropriately exploited. Local data processing through edge computing enables GDPR compliance. Despite this, respondents did not consider GDPR-compliant data processing to be a key motivator for the use of edge computing. However, this interpreted with caution, as not all projects in the technology program involve personal data.

3.2 Challenges

Overall, respondents consider technical factors to be the biggest challenges in implementing edge computing applications. Organizational challenges are seen as the second most significant hurdle. Legal and economic challenges are generally perceived as less significant factors by the respondents.

Ensuring efficient management and orchestration of edge devices

Early adopters rate ensuring efficient device management and orchestration as the biggest challenge in implementing edge computing applications. Device management includes tasks such as configuration, registration, updates, monitoring, deactivation, and removal of edge devices within the overall system. Orchestration refers to the coordination of hardware and software elements of an edge computing application.

In both areas, complexity is primarily caused by the distributed nature and heterogeneity of components in edge computing systems (ISO, 2020). For example, device management tasks, such as performing software updates are much more challenging in edge computing compared to centralized architectures due to its distributed nature. A multitude of devices may be located outside the software supplier's sphere of influence in places with potentially poor network connectivity. Orchestration is particularly challenged by the heterogeneity of hardware and software in the spectrum from edge to cloud. Tasks such as the integration of services and resources, the distribution of individual services across various resources, and the integration of changing hardware or services must be more strongly considered during system design.

Lack of standards to ensure the portability and interoperability of data and components

The early adopters identify the incomplete landscape of standards for interoperability and portability as the second highest (technical) challenge in the implementation of their edge computing application projects. Interoperability refers to the ability to communicate between different devices and services. Portability refers to the ability to move data and services between different infrastructure components with minimal interruptions. Interoperability is particularly crucial in the areas of communication protocols, device identification, nomenclature and definitions, and with respect to data formats. Portability is especially important for implementing services on various edge computing devices at user sites and and for enabling the exchange of edge computing infrastructure when necessary. Additionally, data portability is a legal requirement introduced by the European Data Act.

Standards for interoperability and portability are currently limited. Further, their scalability to a potentially infinite number of edge computing devices is an issue in some cases. In addition, existing standards are currently not supported by all component manufacturers or service providers. Another issue is the interoperability of the standards themselves. As a result, early adopters must invest significant effort in developing their own models or creating bridging technologies to interconnect data and components.

Low level of maturity of technical instruments or components for realizing data sovereignty

Respondents also view the technical realization of data sovereignty as a major complexity factor in their projects. Data sovereignty is the ability of data providers to decide what happens to the data they collect. This includes the transfer of data to third parties for further processing. Data sovereignty is an important requirement for companies using digital services, as they are concerned about inadvertently exposing trade secrets or disclosing personal information through data sharing.

To enforce data sovereignty in data-sharing applications, technical and professional tools are being designed by initiatives such as the International Data Spaces or Gaia-X. The implementation of these technical tools in open-source initiatives is still a work in progress. As a result, early adopters lack lessons learned, best practices, and implementation guidelines from completed endeavours. For example, it is unclear which tools are available and how to apply them in a given application scenario.

Poor availability of specialists and expertise

The insufficient availability of professionals with expertise in edge computing and adjacent areas was identified as the greatest non-technical challenge in implementing edge computing use cases. Edge computing and other adjacent technologies (such as cloud computing, IoT, or AI) are relatively new concepts. As a result, experts in designing, developing, and operating edge computing applications are still in short supply.

This situation is in line with a trend across the entire information technology sector. According to industry association Bitkom, the shortage of IT professionals in Germany has been steadily worsening for some time. In 2022, Germany faced a shortage of "137,000 IT experts across all industries" (Bitkom e.V., 2022). Moreover, compared to other sectors, the information technology sector has the highest proportion of vacancies that cannot be filled (Hickmann, 2022).

Reservations regarding the ability to integrate into existing processes and workflows

Early adopters see another significant organizational challenge in prevailing reservations with respect to the integrability of innovative edge computing applications into existing process workflows. The deployment of innovative edge computing applications may disrupt existing workflows that were previously supported by the existing system landscape of an organization. Often, only specific subtasks are taken over by edge computing applications, and therefore a complete replacement of existing systems is not necessary. Instead, the application must be technically, organizationally, and culturally embedded in existing processes and workflows.

The technical integration of these applications may be hampered by proprietary interfaces and data models of enterprise information systems. From an organizational perspective, process automation can lead to the discontinuation or modification of roles and tasks. Redefinition and rescheduling of roles or tasks may raise employee acceptance issues, as individuals may feel that their roles are being diminished or that they are being asked to perform new tasks that were not previously anticipated.

Further insights: low fear of vendor lock-in and reduced data security

Based on the survey results, some factors currently pose little or no challenge for early adopters when implementing edge computing applications. These include the fear of a vendor lock-in, securing the freedom-to-operate, and ensuring long-term data security. The first two facts are surprising given that the currents standards for interoperability and portability were identified as insufficient. It can therefore be assumed that, in contrast to cloud computing, lock-in effects currently play a minor role in the considerations of early edge computing adopters. Concerns about data security appear to be less prominent for early adopters due to local data processing, although some security mechanisms may be challenged in edge computing because of the limited availability of computing power.

4 Recommendations for the Definition of Edge Computing Use Cases

This section derives recommendations for defining edge computing use cases from the experiences of the early adopters in the technology program Edge Data Cconomy. The recommendations are structured into the steps of "status quo analysis", "idea generation" and "feasibility analysis", which typically need to be executed when defining innovative products and services. Figure 7 shows an overview of these recommendations.

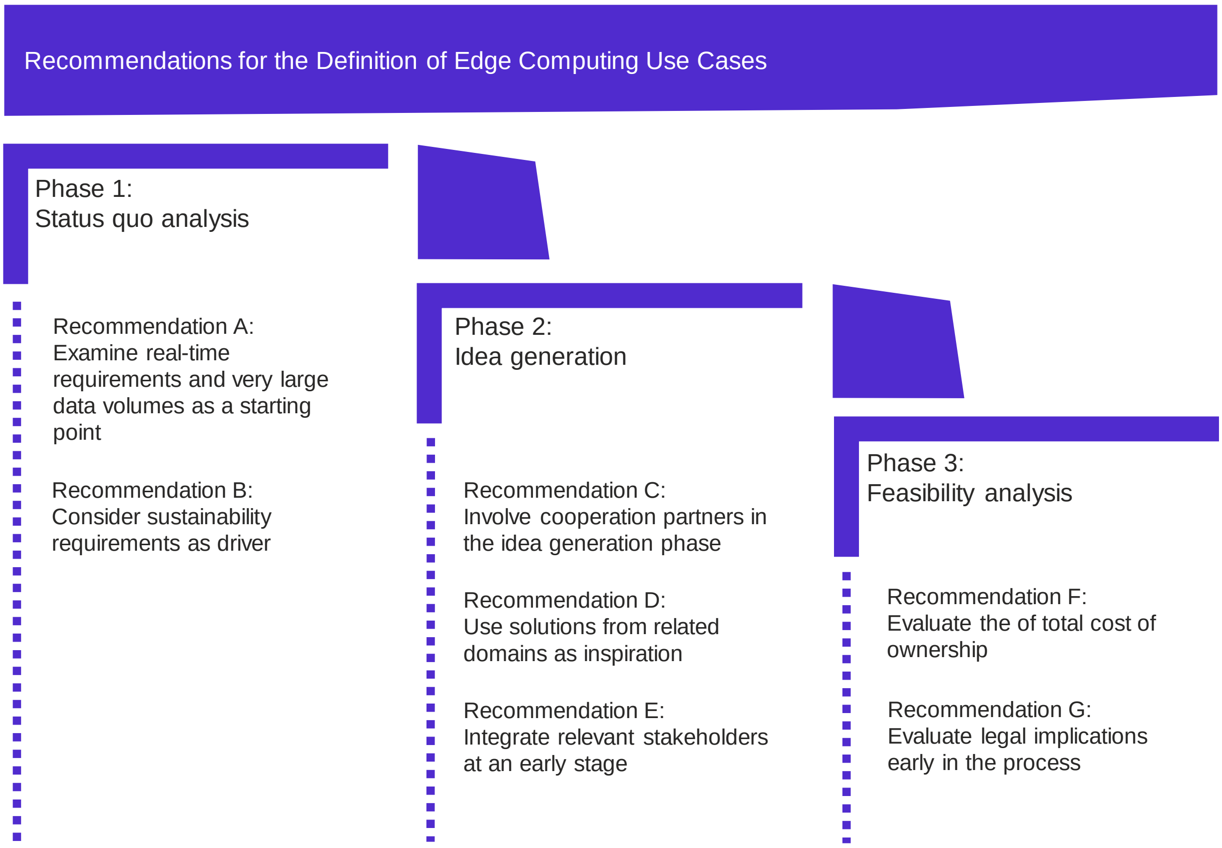


Figure 7. Recommendations for the definition of edge computing use cases

Phase 1: Status quo analysis

The first step in developing a use case is to examine the current state of the business, the current business models and products, the target audience, and the market. This includes identifying untapped potential, both internally and at customers, and analyzing the business ecosystem. As a result, the project team should have a comprehensive understanding of existing business models and processes, future user pain points, and the business environment.

Recommendation A: Examine real-time requirements and very large data volumes as a starting point

The positioning of storage and computing power close to the point of data creation is a key feature of edge computing. The resulting technical benefits, such as low latency in data analysis and local data processing, have been identified both in the literature and by the early adopters in this study as important motivational factors for the use of edge computing.

Accordingly, business areas where low latencies or even real-time requirements and extreme data volumes preclude the use of conventional IT infrastructures should be considered as potential fields of edge computing application. Identifying these areas requires collaboration between technical roles and domain experts, such as product management teams. This can be done, for example, by analyzing existing value chains and the data generated and used within a specific business unit. The first step is to map the existing value chains and their process steps, and to identify information and decision needs. Based on this, the data available at each process step isidentified and data maturity is assessed. By merging information needs and available data, it becomes possible to identify where there are requirements for low latencies or processing large amounts of data that cannot be met by the conventional IT infrastructure.

Recommendation B: Consider sustainability requirements as drivers

Historically, the development of use cases has primarily focused on financial metrics, such as productivity or return on investment. However, environmental, sustainability, and governance aspects (ESG) are increasingly taking center stage in the development of value propositions (Pieroni et al., 2019). Consequently, companies are working towards decoupling value creation from resource consumption.

ESG factors should therefore be given greater attention in the development of edge computing use cases. Integrating ESG criteria in the status-quo analysis helps to identify sustainability issues and opportunities for improvement. Various tools are available for analysing existing business models with respect to ESG criteria (Bhatnagar et al., 2022). These tools typically use assessment methods based on multiple criteria (Multi-Criteria Decision Making). To perform these assessments, it is necessary to identify the sustainability dimensions to be analysed and to define or select appropriate assessment metrics. The United Nations Sustainable Development Goals can be used to identify sustainability dimensions. Specific metrics can then be selected depending on the specific use case. Such metrics include total energy consumption or product lifetime. During the analysis, it is important to take a holistic (systemic) approach, including potential externalities. Often, examining the life cycle of a product or service is a useful approach.

Phase 2: Idea generation

Based on the status quo analysis, the organization defines the vision and building blocks of the novel solution. New ideas can be generated not only from the potentials of using edge computing but also from challenges within existing business models. As a result of this phase, one or more promising edge computing use cases should be defined at a conceptual level.

Recommendation C: Involve cooperation partners in the idea generation phase

As found in previous studies (Gole et al., 2023) and confirmed by the results of this study, few companies have competencies in all areas relevant for implementing edge computing applications (hardware, software, communication technology, and services). Further expertise in specialized areas such as AI or digital twins is often required to implement individual aspects of these solutions. As a result, less digitized SMEs in particular are unable to implement edge computing applications on their own. Potential collaborative partners must be involved in the development of edge computing use cases, ideally in the early stages.

Prior to talking to potential partners, competence needs should be determined. For the systematic determination of required external competencies, capability maps from the area of enterprise architecture management can be utilized. Capability maps define the capabilities needed to realize edge computing use cases and structure them along core functions or the value chain. A company can then assess the individual maturity level regarding these capabilities to identify potential knowledge gaps. Based on these needs, partners can be identified, evaluated, and selected for collaboration. Before collaboration, arrangements such as confidentiality or partnership agreements should be made to protect the information shared and regulate the handling of intellectual property. Finally, various methods for collaborative ideation are available. Examples include Design Thinking, which focuses on developing innovations based on user needs, or the SCAMPER method, which is used for further development of existing applications.

Recommendation D: Use solutions from related domains as inspiration

Unlike generic cloud computing services that are adapted or extended to meet domain-specific needs, edge computing solutions are highly domain-specific by design. For example, there are many providers of specialized hardware, such as sensors, or providers of domain-specific AI applications. These vendors have specialized knowledge in their respective areas. However, they are limited in their ability to transfer existing solutions to other domains because they lack sufficient market knowledge, have limited resources for implementation, or fear regulatory hurdles.

Therefore, during the ideation phase, special attention should be paid to existing edge computing applications in related domains, as these can be adapted and customized to serve one's own needs. For example, hardware components originally designed for one domain can often be used in environments with similar requirements. Methods of environmental analysis, attending trade shows and conferences, and regular interaction with domain experts are effective for identifying existing solutions in related domains. Once relevant solutions have been identified, use case mapping techniques can be utilized to describe existing use cases and outline the changes needed to design an adapted solution.

Recommendation E: Integrate relevant stakeholders at an early stage

Early adopters identified technical and organizational integration as one of the greatest challenges in the implementation of novel edge computing applications. On one hand, novel edge computing applications challenge established organizational workflows and therefore require the acceptance of all affected stakeholder. On the other hand, edge computing applications generate vast amounts of data, which need to be integrated into the existing enterprise data infrastructure. While acceptance issues need to be addressed from organizational and cultural perspectives, technical competence is required for integration into the data infrastructure.

To foster organizational acceptance of the solution, affected stakeholder groups should be involved early in the application development process. Relevant groups include executive personnel, future users, and operators of the existing IT infrastructure. Early involvement at the executive level can support the alignment of the edge computing innovation with a company's strategy and organizational goals. A commitment from executive personnel to the edge computing innovation project also underscores the importance of the initiative. Involving operators from the IT infrastructure ensures that existing standards, e.g., for data modelling or open-source software, are adhered to, and that the collected data is available for further uses. As the final key element, future users should also be involved early in the development process. Inclusion in the ideation phase allows for user-centered development, increased acceptance of the solution, and visibility of potential ethical implications of the innovation. Data protection or the automation of tasks for productivity enhancement are possible ethical concerns. While internal customers can be easily integrated into the ideation processes, dedicated mechanisms such as co-creation workshops or customer advisory boards are suitable to involve external customers.

Phase 3: Feasibility analysis

Within the feasibility analysis, one or more use cases designed in the previous phase are evaluated from a holistic perspective. Elements such as environmental and market analyses are key components in this step. In contrast to the first phase, the feasibility analysis focuses on the already ideated application scenarios and their economic potential. As a result of this phase, a well-founded decision should be made regarding the further pursuit of the use case based on technical, economic, and other criteria.

Recommendation F: Evaluate the total cost of ownership

Continuously growing data volumes are leading to ever-increasing expenditures for corporate IT infrastructure. With “FinOps” a new discipline emerged to maximize the benefits of cloud computing for the enterprise under consideration of the associated costs. Specifically, FinOps enables finance and IT department to gain transparency into cloud service costs and optimize cloud usage. However, FinOps focuses primarily on the operational expenditure associated with using public cloud services. The initial capital expenditures caused by the deployment of edge computing are currently not considered. To assess the economic viability of an edge computing application, which typically includes various elements along the edge-cloud continuum, both perspectives must be considered to juxtapose the overall costs with the expected revenue or savings.

Relevant costs include those for infrastructure, storage, data transmission and networking, deployment, setup, and maintenance of edge hardware, as well as the cost of using third-party software. The incurred costs need to be forecasted over the entire lifecycle of an application. A detailed overview of resulting costs helps in comparing and evaluating different design options of an edge computing application. For example, financial transparency may inform where to process and where to store certain kinds of data. Moreover, the overall cost calculation provides insights into the design of future pricing models. If the edge computing application significantly changes existing processes and workflows, the efficiency gains or potential reduction of labour expenses should also be included in the total calculation.

Recommendation G: Evaluate legal implications early in the process

A number of legal requirements must be met by the edge computing application to be developed. When personal data is collected, for example, the application must comply with certain data protection regulations. Moreover, the Data Act establishes requirements towards the accessibility and portability of data created in edge computing applications. Liability concerns related to the use of the edge computing application and its components, such as AI models, must also be addressed. Furthermore, it is crucial to ensure that no patents are infringed. Additionally, domain-specific regulations, such as those in critical infrastructures or in healthcare, may apply. Ignoring these requirements during the feasibility assessment could lead to unforeseen costs, project delays, or, in the most severe cases, the termination of the innovation project at later stages.

Accordingly, legal aspects should be considered early in the innovation project. However, before involving costly legal experts, it is important to achieve a certain level of concretization of the edge computing application to ensure effective legal advice. Therefore, it is advisable to integrate internal (if available) or external legal consultants during the feasibility assessment stage. A comprehensive description of the envisioned application is typically a fundamental prerequisite, based on which the legal consultants can conduct their assessment.

References

3DS Outscale, Airbus, Amadeus, Aruba, Atos, Capgemini, CloudFerro, DE-CIX, Deutsche Telekom, Ericsson, German Edge Cloud, GIGAS, Indra, IONOS, IRIDEOS, Leaseweb Global, Magic Cloud, Nabiax, Nokia, . . . Telecom Italia (Eds.). (2021). *European industrial technology roadmap for the next generation cloud-edge offering*. https://ec.europa.eu/newsroom/repository/document/2021-18/European_CloudEdge_Technology_Investment_Roadmap_for_publication_pMdz85DSw6nqPppq8hE9S9RbB8_76223.pdf

Ahmed, E., Ahmed, A., Yaqoob, I., Shuja, J., Gani, A., Imran, M., & Shoaib, M. (2017). Bringing Computation Closer toward the User Network: Is Edge Computing the Solution? *IEEE Communications Magazine*, *55*(11), 138–144. https://doi.org/10.1109/MCOM.2017.1700120

Bhatnagar, R., Keskin, D., Kirkels, A., Romme, A. G. L., & Huijben, J. (2022). Design principles for sustainability assessments in the business model innovation process. *Journal of Cleaner Production*, *377*, 134313. https://doi.org/10.1016/j.jclepro.2022.134313

Bitkom e.V. (2022). *Trotz Krieg und Krisen: In Deutschland fehlen 137.000 IT-Fachkräfte | Presseinformation | Bitkom e. V.* https://www.bitkom.org/Presse/Presseinformation/Deutschland-fehlen-137000-IT-Fachkraefte#_

Büchel, J., & Engels, B. (2022). *Viele Unternehmen sind nicht bereit für die Datenwirtschaft: IW-Kurzbericht 96/2022*. https://www.iwkoeln.de/fileadmin/user_upload/Studien/Kurzberichte/PDF/2022/IW-Kurzbericht_2022-Data_Economy_Readiness.pdf

Bundesverband Digitale Wirtschaft (BVDW) e.V. (Ed.). (2018). *Data Economy: Datenwertschöpfung und Qualität von Daten*. https://www.bvdw.org/fileadmin/bvdw/upload/publikationen/data_economy/ BVDW_Datenwertschoepfung_2018.pdf

Curry, E., Metzger, A., Zillner, S., Pazzaglia, J.-C., & García Robles, A. (Eds.). (2021). *The Elements of Big Data Value: Foundations of the Research and Innovation Ecosystem* (1st ed. 2021). Springer International Publishing; Imprint Springer. https://doi.org/10.1007/978-3-030-68176-0

Demchenko, Y., Los, W., & Laat, C. de (2018). Data as economic goods: Definitions, properties, challenges, enabling technologies for future data markets. *ITU Journal: ICT Discoveries*, *2*(23).

European Commission (Ed.). (2023). *Study on the Economic Potential of Far Edge Computing in the Future Smart Internet of Things: Final Study Report*. https://op.europa.eu/en/publication-detail/-/publication/ff35c457-8f3b-11ee-8aa6-01aa75ed71a1/language-en

Gole, J., Zborowska, E., & Rotaru, A. (2023). *Cloud-Edge-IoT Demand Landscape.* https://doi.org/10.5281/zenodo.7821329

Hickmann, H. (2022). Die Berufe mit den aktuell größten Fachkräftelücken. *IW-Kurzbericht*, Article 67. https://www.iwkoeln.de/fileadmin/user_upload/Studien/Kurzberichte/PDF/2022/IW-Kurzbericht_2022-Top-Fachkr%C3%A4ftel%C3%BCcken.pdf

ISO (02-2020). *ISO/IEC TR 23188:2020:* Information technology — Cloud computing — Edge computing landscape.

Jain, K., & Mohapatra, S. (2019). Taxonomy of Edge Computing: Challenges, Opportunities, and Data Reduction Methods. In F. Al-Turjman (Ed.), *EAI/Springer Innovations in Communication and Computing Ser. Edge Computing: From Hype to Reality* (pp. 51–69). Springer International Publishing AG. https://doi.org/10.1007/978-3-319-99061-3_4

Linux Foundation (Ed.). (2022). *State of the Edge 2022*. https://stateoftheedge.com/reports/state-of-the-edge-report-2022/

Marcham, A. (2021). *Understanding infrastructure edge computing: Concepts, technologies and considerations*. Wiley.

Noghabi, S. A., Cox, L., Agarawal, S., & Ananthanarayanan, G. (2019). The Emerging Landscape of Edge Computing. *GetMobile: Mobile Computing and Communications*, 11–20.

Pieroni, M. P., McAloone, T. C., & Pigosso, D. C. (2019). Business model innovation for circular economy and sustainability: A review of approaches. *Journal of Cleaner Production*, *215*, 198–216. https://doi.org/10.1016/j.jclepro.2019.01.036

EDGE
Datenwirtschaft