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Doctoral Dissertation

A XaaS Roadmapping toward a Decarbonization Society

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ABSTRACT

The acceleration of global economic and industrial activities has substantially intensified the climate crisis, necessitating urgent and deep decarbonization efforts. While existing research has primarily concentrated on technological advancements in renewable energy and carbon capture as strategies to reduce dependency on fossil fuels, such approaches often overlook the multifaceted nature of achieving a decarbonized society, which requires fostering innovation, collaboration, future-oriented thinking, and changes in awareness and behavior. This dissertation introduces an innovative XaaS (Everything-as-a-Service) roadmapping framework that incorporates Futures Literacy (FL) to support the design of service-oriented systems aligned with decarbonization objectives and consumer well-being. The proposed framework expands the scope of traditional roadmapping by emphasizing ecosystem-wide collaboration and forward-looking perspectives. In contrast to traditional technology or service roadmapping approaches, which typically focus on structured planning within industry-specific boundaries , the XaaS roadmapping framework conceptualizes all value offerings as services and promotes cross-sectoral innovation.

The XaaS framework offers a transformative perspective by reimagining conventional business models into service-based operations. This paradigm shift fosters enhanced flexibility, resource circularity, and organizational adaptability. Grounded in principles of transformative knowledge management , the framework facilitates anticipatory governance , collaborative foresight , and stakeholder co-creation. These capabilities collectively empower organizations to construct dynamic and resilient service roadmaps that can respond to volatile policy landscapes, shifting consumer behaviors, and emergent environmental imperatives, enabling them to make informed decisions.

To evaluate the framework, this study adopted a sequential mixed-methods research design encompassing qualitative and quantitative components. The first phase involved the facilitation of knowledge co-creation workshops with domain experts from the engineering and social infrastructure industries. The workshops progressed through four structured stages: ideation, identification of roadmap components, roadmap drafting, and expert validation. Participants employed FL techniques to develop and prioritize service innovation ideas using criteria such as strategic relevance, desirability, viability, and feasibility. Among the concepts generated, “Carbon Credit Trading-as-a-Service” (CTaaS) was identified as a highly promising initiative due to its potential contributions to environmental sustainability, consumer well-being, and business value.

To overcome knowledge space limitations , topic modeling and patent analysis were employed to extract insights from academic publications (Scopus) and patent data. These analyses informed the construction of a multi-layered roadmap comprising four core dimensions: policy, market, technology, and service. The roadmap was further refined using a digital collaboration platform, Miro , to enable real-time feedback and consensus building among stakeholders, ensuring both practical relevance and strategic coherence over a timeline from 2023 to 2050.

In the second phase, a scenario-based simulation was conducted using System Dynamics (SD) modeling to investigate the long-term impacts of the CTaaS roadmap on CO_2 emissions in Japan. SD was selected for its robust capacity to model complex system behaviors and interdependencies, particularly those related to sustainability transitions and organizational and social change. The simulation incorporated policy incentives, technological maturity, consumer adoption rates, and financial mechanisms. Three distinct scenarios were analyzed, namely optimistic, neutral, and pessimistic , to assess the robustness of the roadmap under conditions of uncertainty. Results demonstrated that the CTaaS roadmap could significantly reduce national carbon emissions by 2040 , especially under supportive policy regimes and high public engagement. The system dynamics model provided a comprehensive view of the interactions among policy, behavior, and technology.

This research contributes to theory by extending the XaaS paradigm beyond its origins in information technology to encompass environmental and socio-economic systems. Methodologically, it offers a novel integration of foresight practices and service innovation tools through the combined application of Futures Literacy, roadmapping, and system modeling (including System Dynamics). Practically, the framework serves as a strategic guide for policymakers, enterprises, and innovation practitioners seeking to align operational models with the Sustainable Development Goals (SDGs) and climate mitigation targets. Additionally, it underscores the importance of cultivating Futures Literacy as a foundational competency for navigating complex and uncertain sustainability challenges.

In conclusion, the synthesis of XaaS and Futures Literacy within a roadmapping methodology offers a powerful mechanism for systemic innovation. This approach enables organizations to co-create actionable service strategies that not only respond to environmental imperatives but also support long-term societal transformation. Future research could explore the applicability of this framework across diverse industries and cultural contexts to facilitate global pathways toward a decarbonized future.

Keywords: XaaS roadmapping, Decarbonization, Service roadmap, Knowledge co-creation workshop, Futures literacy

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Chapter 1
Introduction

The global warming phenomenon has a significant impact on the planet, leading to unpredictable climate conditions, water scarcity and the concerning rise of sea levels (Sivakumar, 2011). Countries and corporations have committed to achieving carbon neutrality by 2050, aiming to balance greenhouse gas emissions and removals (Song et al., 2020; Marti and Puertas, 2022). The recent COP29 summit in Baku, Azerbaijan, highlighted the urgent need to transition away from fossil fuels and intensify climate action. COP29 also emphasized key challenges, including the lack of ambition in phasing out fossil fuels, financial gaps, and implementation hurdles (UNFCCC, 2024). To achieve the ambitious goals of the Paris Agreement, innovative business models that drive sustainable transformation are crucial (Trapp *et al.*, 2022). This necessitates a societal transition toward the widespread adoption of clean energy and sustainable consumption behaviors (Boisseau *et al.*, 2018; Cobo-Gómez, 2024; Groves *et al.*, 2023; Lipschutz, 2012). Public perception and behavior change are crucial for achieving a low-carbon future (Wüstenhagen *et al.*, 2007). Technological advancements, environmental concerns, economic considerations, social practices, and community engagement are all crucial aspects of decarbonization and sustainability (Das *et al.*, 2023; Labanca *et al.*, 2020; Rüdele *et al.*, 2024) In addition, policy frameworks are also critical, such as carbon pricing and international agreements, along with the socioeconomic effects of decarbonization (International Labour Organization (ILO), 2018; Stern *et al.*, 1999; Weerasinghe *et al.*, 2024; World Bank, 2023).

The transition to a decarbonized society, defined by the substantial reduction of carbon emissions through the widespread adoption of renewable energy, energy efficiency measures, and sustainable practices, is essential for addressing the root causes of the climate crisis and achieving long-term environmental stability characterized by increased reliance on renewable energy and reduced carbon emissions, is crucial for mitigating the climate crisis (Hondroyiannis *et al.*, 2024; Lund *et al.*, 2022; Wimbadi and Djalante, 2020). The majority of research has focused on technological advancements in renewable energy and carbon capture to reduce reliance on fossil fuels (IRENA, 2021; Wesseling *et al.*, 2017; Zaghdoud, 2025). While technological advancements in renewable energy and carbon capture are crucial, achieving a rapid and equitable transition to a decarbonized society requires a multifaceted approach that fosters innovation, collaboration, future-oriented thinking, and changing the awareness and behavior (Terashima, 2024). This requires a fundamental change in business operations and consumer engagement with products and services.

Everything-as-a-Service (XaaS) offers a potential solution. XaaS is a service paradigm that focuses on social engagement and transitions from ownership to access. The XaaS model encourages businesses to share resources efficiently, making it an attractive option for investors and shareholders (Bhattacharya and Bhattacharya, 2021; Singh *et al.*, 2022). The increasing demand for flexibility, scalability, and cost-efficiency drives XaaS adoption, supported by advancements in cloud computing, big data analytics, and artificial intelligence (Duan *et al.*, 2016; Lackermair, 2011; Rimal *et al.*, 2011). A decarbonized society, characterized by low-carbon systems and sustainable practices, necessitates transformative strategies in business, governance, and societal perspectives. Futures literacy is the ability to imagine and strategize for diverse futures, which is a crucial competency for managing the intricacies of decarbonization. It enables stakeholders to anticipate disruptions, assess sustainable technologies, and make educated decisions that align with long-term climate goals. The integration of XaaS models, which emphasize service delivery over product ownership, significantly enhances the possibility for accelerating decarbonization. However, there are challenges to XaaS adoption, such as technological readiness, organizational resistance, and policy inadequacies.

This dissertation aims to overcome the limitations of current decarbonization efforts by introducing a novel XaaS roadmapping framework. This framework is based on the principles of transformational knowledge management and futures literacy. It provides a strategic approach for organizations to identify and develop innovative services that contribute to a society with reduced carbon emissions. The proposed XaaS roadmap aims to facilitate value constellation by clarifying the complex interdependencies of services and technologies within the broader organizational and inter-company ecosystem to create a more sustainable future.

Research background

The Sustainable Development Goals (SDGs) represent the collective impact of the ongoing economic expansion on the environment. It is imperative that we shift attention towards fostering a economic growth and restoring ecological balance (Xu et al., 2022). At the 47th G7 Summit in Cornwall, England, there was a discussion on the significance of financialization, as highlighted in a recent publication by Oxfam (2021). Experts have warned that the G7 economies could face a significant decline in wealth if they fail to address climate change. Japan, as a member of the Group of Seven (G7), holds the position of the fifth-largest carbon emitter globally. It has a significant population ranking 11th largest population and the 63rd largest land area (Crippa et al., 2022; Ritchie et al., 2020). The commitments by enterprises and nations to achieve carbon neutrality by 2050 emphasize the urgent need for rapid decarbonization in all areas of society. It raises the question of where the industry will continue to grow while decarbonizing.

To find solutions for the issues, most countries commonly set targets for measuring carbon emissions in production-based emissions (Davis & Caldeira, 2010; Miura et al., 2021). Consumption-based carbon emissions, on the other hand, are higher than production-based emissions (Ritchie et al., 2020). Therefore, we need to reduce consumption-based CO_2 emissions by creating service ideas that expand consumers' choices. The research agenda of transformative knowledge management focuses on the concept of knowledge as a transformative resource for building a society for future generations. It emphasizes the need for businesses to adapt to changing environmental conditions, regulations, emerging technologies, and shifting consumer behavior to identify opportunities for success and ensure the future well-being (Kononiuk et al., 2021). This is consistent with UNESCO's advocacy for futures literacy. As a result, this study focuses on how to use the future to create sustainable services with the goal of reducing carbon emissions.

1.1 Research objectives

The objective of this research is to develop a service innovation roadmap that will foster a shift in consumer mindset by cultivating knowledge creation capability in order to co-create XaaS for a decarbonized society and consumer well-being.

This study's results aim to assist service innovation businesses in identifying opportunities to transform their operations to meet future customer expectations and achieve sustainability.

1.2 Research Questions

The research questions of this study are as follows:

1. How can knowledge management be transformed into creating sustainable value for society?
2. How can we empower people to use the future to develop service innovation roadmap for decarbonization society and consumer well-being?

1.3 Structure of Dissertation

This research develops a novel roadmapping approach that focuses on utilizing the future to create sustainable services with the goal of reducing carbon emissions.

The research consists of seven chapters. We describe the main content of each chapter below.

Chapter 1 provides an overview of the research background, research objectives, research questions, and structure of the dissertation outline.

Chapter 2 is a review of the literature. This chapter discusses theoretical background and research methodology.

Chapter 3 provides an explanation of the methodology.

Chapter 4 provides the findings of Study A: Knowledge co-creation workshop for XaaS roadmapping toward a decarbonized society and consumer well-being.

Chapter 5 discusses the findings of Study B: Scenario development and how they relate to Study A.

Chapter 6 includes the research conclusions and discussions.

Chapter 7 addresses the limitations and recommendations for further study.

Chapter 2
Literature Review

2.1 Decarbonization

Principal strategies for transitioning towards a carbon-neutral society encompass increasing dependence on renewable energy sources and reducing carbon emissions to address the climate crisis. These actions are imperative for addressing the climate crisis (Wimbadi & Djalante, 2020). This transition also has a direct correlation with the consumers' well-being. Eco-innovation emerges as a pivotal strategy in reducing carbon emissions and mitigate climate change (Pérez-Pérez et al., 2021). Innovations in renewable energy and carbon capture are two key technologies that have received a lot of attention from the research community. Renewable energy sources, including solar, wind, and hydropower, are becoming more common due to their significant potential to reduce the use of fossil fuels (IRENA, 2021; Wesseling et al., 2017; Ahmed et al., 2021). Furthermore, the construction sector requires eco-efficient construction materials and solutions that prioritize the principles of circular economy and resource efficiency (Mercader-Moyano & Esquivias, 2020).

Several studies have examined the socioeconomic implications of decarbonization, particularly in relation to job creation and fairness concerns. These studies have focused on policy frameworks such as international agreements and carbon pricing, providing valuable insights into the topic (International Labour Organization (ILO), 2018; Stern et al., 1999; World Bank, 2023). It is widely acknowledged that changing public attitudes and behaviors is essential for the establishment of a climate-friendly economy (Wüstenhagen et al., 2007).

There is an increasing emphasis on service innovations that address the consumer' s well-being, including their physical, emotional, and psychological aspects. This has strengthened the connection between reducing carbon emissions and enhancing well-being (Gustafsson et al., 2005; Jaakkola et al., 2015). This shift in paradigm necessitates a more profound understanding of customer needs, preferences, and values, driving the advancement of service innovations.

Although there has been considerable progress in understanding the routes to decarbonization and enhancing consumer well-being, there remain numerous challenges to overcome. More research and efforts are required to ensure a fair and sustainable transition and to foster public participation.

2.2 Futures Literacy

In today's rapidly changing world, it is imperative for businesses to continually innovate to capitalize on opportunities and foster growth. According to Lopez (2012), innovation serves as a crucial role in securing a competitive advantage and acts as the driver for economic expansion. Nonetheless, the dynamic nature of environmental conditions, regulatory frameworks, emerging technologies, and shifting consumer behavior presents significant challenges in ensuring sustained viability and success (Haarhaus & Liening, 2020).

Futures Literacy (FL), advocated by UNESCO, has emerged as a critical tool for businesses to navigate uncertainty (Miller, 2018a). UNESCO addresses the pressing need to transform human governance by empowering all to use the future more effectively and efficiently. Its purpose is to prepare for potential crises, overcome major challenges, and accomplish the fundamental goals of Agenda 2030. FL is a cognitive competency that enables individuals and organizations to engage with the future in increasingly complex ways (UNESCO, 2021).

In the context of transformative knowledge management, Anticipatory Assumptions (AA) constitute a form of tacit knowledge that guides the envisioning of futures (Miller, 2018a). Miller (2018) proposes two distinct types of anticipatory systems. All humans have embedded the relevant anticipatory systems (AS) and related Knowledge Creation Processes (KCP) in a desired future, termed Anticipation-for-the-

Future (AfF), since they first developed common sense. Conversely, anticipation-for-emergency (AfE) is a knowledge creation process that envisions the future by making sense of existing but otherwise invisible emergent novelties or inventions. Hence, both components are essential.

FL enhances organizational resilience and adaptability, enabling businesses to anticipate and navigate by cultivating an understanding of diverse possible futures and challenging preconceived notions (Karjalainen et al., 2022; Toivonen et al., 2021). This cognitive competency fosters innovation and enhances an organization's ability to anticipate, rejuvenate, and adapt to change (Boonswasd & Shirahada, 2022; Mangnus et al., 2021). FL has successfully supported revolutionary business strategies, aiming to identify and explore disruptive business opportunities (Cagnin, 2018; Karjalainen et al., 2022). FL is a multidimensional cognitive capability enabling individuals and organizations to engage with potential future scenarios in a more advanced and complex way. Miller (2007) outlines three distinct levels of FL: Awareness, Discovery, and Choice.

Level 1, Awareness, focuses on fostering temporal and situational awareness. It helps individuals recognize the inevitability of change and understand how various stakeholders perceive and value the future. This is accomplished through a range of techniques that encourage discussion, storytelling, and the explicit articulation of values and expectations.

Level 2, Discovery, involves the careful use of imagination to explore possibilities beyond conventional boundaries, while maintaining analytical rigor. This necessitates systematic creativity and the application of social science methods to explore potential futures beyond the constraints of current assumptions and preferences.

At Level 3, Choice incorporates the knowledge gained from the previous levels to guide strategic decision-making. By combining values, expectations, and possibilities into strategic scenarios, individuals and organizations can critically assess current choices, anticipate potential consequences, and make informed decisions that align with their desired futures.

The progressive development of futures literacy, through its three levels and associated techniques, facilitates a structured approach for envisioning and realizing innovative business opportunities.

2.3 XaaS (Everything-as-a-Service)

Everything-as-a-Service (XaaS) is a paradigm shift in the business landscape, revolutionizing the delivery and consumption of products and services. This includes various models such as software, platform, infrastructure, mobility, and healthcare-as-a-Service (Fardinpour et al., 2020; Humayun et al., 2022; Butler et al., 2021; Faruqui et al., 2023; Wong et al., 2020). The demand for flexibility, scalability, and cost-efficiency, coupled with advancements in cloud computing, big data analytics, and artificial intelligence, are key drivers behind XaaS adoption (Lackermair, 2011; Rimal et al., 2011; Duan et al., 2016).

XaaS emphasizes the shift from product ownership to service access, encouraging shared resource utilization, a key element of a circular economy . Investors and stockholders are increasingly interested in XaaS and platform-based business models, which offer numerous advantages in decarbonization efforts, including reduced initial costs, improved adaptability, and reduced waste (Singh et al., 2022; Bhattacharya & Bhattacharya, 2021). Diverse industries are adopting XaaS solutions in decarbonization initiatives, such as renewable energy delivery, solar panels and wind turbines, and electric cars. The integration of subscription-based and pay-per-use models for charging could decrease initial costs associated with the shift towards renewable energy or EVs, while offering increased mobility (Bocken et al., 2018; R. Miao et al., 2022; Rajesh et al., 2012).

XaaS adoption offers numerous advantages, such as cost reduction, enhanced organizational agility, accelerated innovation cycles, superior customer experiences, and the ability to adapt to volatile market conditions (Day & Schoemaker, 2016; Ganapathy, 2020). It also plays a significant role in mitigating carbon emissions and fostering sustainable practices by leveraging cutting-edge technologies without substantial capital investment.

The shift to XaaS necessitates enterprises to adopt a service-oriented culture and a dedication to ongoing innovation (Grönroos, 2024). The transition to the XaaS model, while promising, presents businesses with several implementation challenges. It demands a cultural and operational shift within organizations, requiring the adoption of a service-oriented mindset and potential restructuring of existing business models

(Teece, 2018). This transformation can be complex and resource-intensive, posing a significant hurdle for businesses. Moreover, the success of XaaS is contingent upon robust technology and infrastructure, any disruptions or limitations can negatively impact service delivery and customer satisfaction (Bhattacharya & Bhattacharya, 2021). Additionally, the increased reliance on data sharing and cloud-based solutions inherent to XaaS models raises concerns about data security and privacy, necessitating stringent measures to protect sensitive customer information (Abreu, 2021).

2.4 Roadmapping

Roadmapping is a systematic and strategic approach used to develop and introduce new product or service offerings. The structure comprises multiple interrelated levels, each of which focuses on essential aspects of product and service development and delivery (Cho & Lee, 2014; J. H. Lee et al., 2013; Suh & Park, 2009; Wells et al., 2004).

2.4.1 Technology Roadmapping

Technology Roadmapping (TRM) is an essential approach for facilitating collaborative technology planning and coordination, which can be applied to both individual corporations and entire industries. The statement refers to a particular approach to technology planning that is in line with a wider range of planning activities (Garcia & Bray, 1997). The technology roadmapping approach exhibits considerable flexibility, accommodating diverse organizational objectives and a variety of graphical representations that roadmaps can adopt (Phaal, 2004). Nevertheless, traditional TRM has limitations, particularly in terms of the partial utilization of the scenario development method and a lack of future exploration (Hussain et al., 2017). The limited lifespan of TRM restricts its role in the sustainable development approach. Y. Zhang et al. (2016) introduced a hybrid TRM, leveraging qualitative expert knowledge and quantitative text analysis from science, technology, and innovation data, to obtain competitive technological information for broader future visibility. Additionally, a scenario-based technology roadmap exists that primarily considers environmental uncertainty based on an expert workshop, as opposed to big data (Son et al., 2020).

2.4.2 Service Roadmapping

Service roadmapping constitutes a technology-driven process that initiates with capability analysis for technology planning and ends with a business opportunity analysis for market planning (Daim et al., 2018). It also serves as an effective communication tool for discussing all possibilities and formulating future service concepts. Its emphasis on macro-level planning for a certain future period, concentrating on the integration of service systems with other business factors such as vision, markets, and technology. Cho & Lee (2014) proposed five distinct types of service roadmap architectures, namely: 1) product-based service roadmaps, 2) market-driven service roadmaps, 3) service-technology roadmaps, 4) technology-based service roadmaps, and 5) product-service integrated roadmaps.

Organizations have relied on distinct roadmapping approaches such as technology roadmapping (Phaal, 2004) for guiding technological development and service roadmapping (Cho & Lee, 2014; Suh & Park, 2009) for charting the evolution of service offerings. Furthermore, the combination of products, services, and technologies has resulted in the creation of integrated roadmaps, such as the product-service roadmap and service-device-technology roadmap, which bring together both technological and service perspectives (An et al., 2008; J. H. Lee et al., 2013). Kim and Geum (2021) introduce a technology roadmap based on data analysis. Agile roadmapping, moreover, offers a flexible framework for adapting to the dynamic nature of Digital Entrepreneurship (DE), particularly in volatile industries and ongoing changes in strategy (De Souza et al., 2022).

Traditional roadmapping approaches, such as Technology Roadmapping and Service Roadmapping, have certain limitations that hinder their ability to promote innovation and address the complex challenges of sustainability and decarbonization. The existing difficulties include a lack of integration between technology and service perspectives, inadequate stakeholder engagement, limited focus on sustainability, and difficulty in adapting to the dynamic complexity of the modern business environment (Carvalho et al., 2013; Phaal, 2004). The implementation of XaaS concept will bridges these gaps by integrating between technology and service, promoting collaboration among stakeholders, explicitly considering sustainability.

2.4.3 Electronic Roadmap

Electronic roadmaps facilitate efficient communication among geographically dispersed teams by providing real-time updates, version control, and integration with project management systems (Ateetanan & Shirahada, 2018). Integrating visualization elements and user stories enhances communication and increases stakeholder support. Miro, a multifunctional digital whiteboard platform, is increasingly being preferred as a tool for conducting e-roadmapping workshops. The real-time editing varied visual tools, voting, and commenting features facilitate effective brainstorming, organization of roadmaps, and consensus formation (Aravind, 2023; Miro, 2023).

Although there is limited study on the specific application of Miro in electronic roadmapping workshops, studies on collaborative roadmapping provide valuable insights. De Oliveira et al. (2022) examined the effectiveness of collaborative roadmapping workshops within the context of strategic roadmapping. According to their research, workshops that utilize online collaboration tools could greatly improve the development of strategic narratives, particularly during the articulate stage. Similarly, Manuel et al., (2023) explored the application of collaborative online whiteboards in a complex roadmap for coastal ecosystems. Their study emphasizes the advantages of utilizing visual tools and real-time editing to foster creative thinking and achieving shared understanding within teams. Nevertheless, it is crucial to carefully evaluate difficulties such as excessive amounts of information and concerns regarding the security of data.

Electronic roadmaps offer a dynamic and collaborative approach to strategic planning, while Miro software provides a valuable platform for facilitating collaborative roadmapping workshops. The combination of electronic roadmaps and Miro's features allows teams to brainstorm ideas, visualize plans, and achieve consensus in real-time. Future research specifically investigating the effectiveness of Miro in electronic roadmapping workshops would be beneficial to further solidify the empirical foundation for this practice.

2.4.4 Scenario development

Scenario planning is a strategic strategy that helps explore alternative scenarios in the future and their implications in various conditions. It is crucial for making informed decisions (Postma & Liebl, 2005). The formulation of scenario-based roadmaps entails a systematic process that incorporates a range of conceptual and cognitive methodologies. Cheng et al. (2016) propose a five-phase approach emphasizing the significance of scenario development. This strategy involves the use of organized guidelines, such as the Six Thinking Hats method and the Kipling Method (5W1H), to generate diverse scenarios. Imeri et al. (2016) emphasize the importance of incorporating legal and ethical considerations through compliance. Furthermore, Son et al. (2020) propose the application of Fuzzy Cognitive Maps (FCMs) to construct and simulate potential outcomes of various situations, thus aiding in the process of decision-making and strategic planning.

Incorporating scenario development into XaaS roadmapping leverages the advantages of both technology and service roadmaps. By considering a broad spectrum of potential future scenarios, companies may actively recognize emerging opportunities and challenges and ultimately generate greater value for both users and stakeholders. A forward-thinking and adaptable strategy for service innovation in the context of XaaS, considering rapid technological progress and evolving customer expectations

The integration of behavioral economics and social innovation principles into scenario development can lead to the creation of service offerings that are both environmentally sustainable and socially responsible (Aksoy et al., 2019; Schmidt & Stenger, 2021). The effectiveness of these strategies can be further enhanced by incorporating scenario planning, a strategic tool that allows for the exploration of alternative future scenarios and their implications under various conditions (Postma & Liebl, 2005). By considering a range of potential future scenarios, organizations can proactively identify emerging opportunities and challenges, develop adaptable strategies, and ultimately create greater value for both users and stakeholders. The scenario development process can be guided by established frameworks and incorporate collaborative workshops with industry experts and stakeholders to ensure a holistic and multi-faceted perspective.

2.5 System Dynamics

System Dynamics (SD) is a methodology employed to construct models and examine complex systems. It is frequently used to address issues related to organizational and social change, including sustainability, innovation, and performance (Sterman, 2000). SD theory, originating from the work of Professor Jay Forrester at the Massachusetts Institute of Technology, is a computer-assisted approach that analyzes system behavior to explore potential futures (Zsifkovits et al., 2016; Meadows, 2009). It is commonly applied to complex systems, using a simulation technique to study the system behavior and influences over time (Geum et al., 2014). The nonlinear and dynamic behaviors of complex systems are captured using mathematical models. It is possible to comprehend and predict a system's response to changes in its environment or internal structure by analyzing feedback loops and interactions (Sterman, 2004).

As Forrester (2007) clarifies, a system variable has a historical trajectory leading up to the current decision time. In the short term, this trajectory is characterized by continuity and momentum, which mitigates deviation from previous forecasts. A system dynamics model that is constructed properly can be used to predict the unique system behavior that is the result of diverse policy decisions (see Figure 2.1).

SD does not necessitate a predetermined model but rather is grounded, which varies depending on the topic under study (Pérez-Pérez et al., 2021). It can be used to identify and evaluate key drivers of change within an organization or industry,

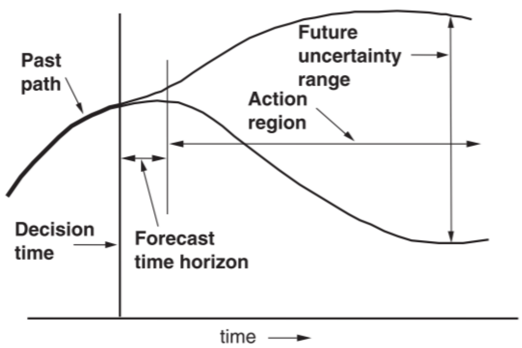

Figure 2.1 Forecasting versus action (Forrester, 2007b)

encompassing internal factors such as technological advancement and market trends, as well as external factors such as regulatory changes and economic conditions (Forrester, 2007b).

The literature review indicates that System Dynamics (SD) is a powerful tool for modeling complex systems, particularly those undergoing change. The simulation of system interactions and feedback loops facilitates the exploration of potential future scenarios. The application of system dynamics to the examination of scenario-based simulation could provide invaluable insights for strategic decision-making in complex and evolving contexts. The related work is referenced from various research as shown in Table 2.1

The SD-based methodology is outlined in the following stages (Pérez-Pérez et al., 2021; W. Zhang et al., 2021). The first stage involves identifying the problem. In stage 2, identification of hypotheses and system boundaries are represented by causal feedback loops and stock-flow diagrams. Stage 3 follows, which involves developing models using mathematical principles and simulation techniques. The mathematical model will be represented by a stock-flow diagram that is constructed and illustrated. The diagrams illustrate the system's feedback loops. During the formation of a mathematical model, the equations are derived and determined based on the structure of the model, which includes the auxiliary variables and parameters used to clarify the model.

The time integrals of the net flows are then used to generate the stock equations, while the flow equations are formulated based on the time functions and system parameters of the stocks. This stock-flow diagram is solved through simulation using a series of differential equations, owing to its intricate nature. Then is stage 4, which involves testing the model’s behavior. The final stage involves formulating policies or strategies and conducting evaluations.

Table 2.1 Literature Summary on Applying System Dynamics to Evaluate Innovation Outcome.

Industry	Focused research	RM Approach	Source
Steelworks	Economic feasibility analysis of carbon capture technology.	N/A	(Yao et al., 2021)
Energy	Multi-level factors influencing national energy-related carbon emissions and technology innovation scenarios.	N/A	(Yang et al., 2021)
Transportation Infrastructure	Project evaluation based on a cost-benefit analysis.	N/A	(Nguyen et al., 2017)
Car-sharing service	Scenarios evaluation	Scenario-based TRM	(Geum et al., 2014)
Car-sharing service	Scenarios evaluation	N/A	(Nieuwenhuijsen et al., 2018)
National Innovation System (NIS)	Impact on innovation policy and performance in different scenarios.	N/A	(Samara et al., 2012)
Healthcare system	Funtional dynamics of product-service system and its scenaios.	N/A	(Sora Lee et al., 2015)
Industrial entreprise	Multi-scenario simulation on low-carbon sustainale development.	N/A	(W. Zhang et al., 2021)

Source(s): Created by authors

2.6 Research gaps and a position of this research

The research focuses on futures literacy and roadmapping into XaaS business strategy and its ecosystem. While existing research emphasizes the distinct advantages of these principles, it does not explore their synergistic application. The majority of roadmapping literature focuses on technology and service strategy, however, there is an opportunity for more exploration of the business ecosystem.

Recent empirical studies strengthen the study by demonstrating real-world applications and barriers to XaaS and Futures Literacy (FL) adoption across sectors. For example, Mortensen et al. (2021) discussed corporate resistance to FL, emphasizing the difficulty of integrating future-oriented strategic thinking into XaaS innovation. Wang et al. (2024) provided finding from Farming-as-a-Service (FaaS) in Agriculture 4.0, indicating that personalization, financial benefits, and network effects drive adoption, whereas perceived risk and regulatory inconsistencies hinder it. Yadav et al. (2020) identified trust issues and technological barriers as key challenges in blockchain-enabled models, which align with broader adoption concerns in service-oriented sustainability frameworks. Fernando et al. (2023) discovered that in the manufacturing sector, the adoption of blockchain technology for carbon trading is impeded by factors such as firm size and compatibility issues.

These findings underscore the necessity for roadmapping strategies that integrate FL methodologies to anticipate challenges, align multi-stakeholder interests, and facilitate XaaS-driven transformations to improve the scalability and efficacy of XaaS models in service-oriented and sustainability-centric sectors.

Recently research explores the role of digital and green servitization in technological innovation and cleaner production, respectively (Rabetino et al., 2024; Upadhayay et al., 2024). These studies highlight the increasing importance of service-oriented models in achieving decarbonization goals. Additionally, there are alternative paradigms like product-service systems based on life cycle assessment results and rental clothing schemes as sustainable alternatives to traditional models (Herold & Prokop, 2023; Neramballi et al., 2020). These research investigations offer helpful perspectives on how different service-oriented approaches can contribute to decarbonization efforts.

Furthermore, Johl et al. (2024) examine the interplay between green servitization, the circular economy, and sustainability in achieving sustainable performance. This research emphasizes the importance of integrating green initiatives and circular economy principles to enhance operational performance and sustainability.

Recognizing this gap, this study introduces a new XaaS roadmap, which conceptualizes all offerings as services, aligning with the XaaS paradigm. The proposed XaaS roadmap is grounded in understanding customer needs, market trends, and technological advancements. Its primary objective is to help organizations identify emerging service opportunities and design an innovative XaaS ecosystem. This roadmap is built upon existing roadmap frameworks but is specifically tailored to accommodate the unique attributes of XaaS. It contributes to the ongoing discussion on service innovation in the context of carbon neutrality. The roadmap also uses electronic tools for real-time communication, version control, and integration with project management systems. Visual tools like timelines and user stories enhance communication and stakeholder engagement (Miro, 2023; Oliveira et al., 2021).

By incorporating the three levels of FL, knowledge co-creation workshops can effectively harness the expertise and foresight of participants. This enables the development of strategic roadmaps that are responsive to evolving market trends and technological advancements and shaping the future of XaaS in alignment with the desired outcomes.

Chapter 3
Research Methodology

3.1 Research Design

This research presents the XaaS roadmap framework, which integrates futures literacy to anticipate future services that contribute to the establishment of a decarbonized society. The research design in this dissertation employs a sequential mixed-methods approach, which involves conducting two distinct but interconnected studies in a sequential manner (Creswell & Clark, 2017).

1) XaaS Roadmapping Framework

The initial study adopts an exploratory and qualitative approach, primarily utilizing case studies to delve into the relationship between foresight methodologies and the outcomes of the roadmap. The core of this study focuses on developing the XaaS roadmapping framework through a knowledge co-creation workshop. It aims to demonstrate the feasibility and effectiveness of the framework in generating innovative XaaS ideas and constructing a roadmap for decarbonization.

2) Scenario-based simulation

The subsequent study utilizes scenario analysis and system dynamics modeling upon the XaaS roadmap developed in the first study. This study adopts a quantitative and predictive approach, aiming to assess the long-term effects of the XaaS roadmap on decarbonization efforts.

3.2 XaaS Roadmapping Framework

Cultivating futures literacy within organizations is crucial for effectively navigating the complexities of the business landscape and anticipating future opportunities and challenges. This involves equipping individuals with the capacity to think critically and creatively regarding the future, utilizing tools such as trend and scenario analysis (Miller, 2007; Kononiuk et al., 2021). By honing future-oriented capabilities, such as synthesizing external data with imaginative insights, businesses can proactively recognize emerging trends, anticipate potential disruptions, and come up with informed decisions that are in line with their strategic goals (Rohrbeck, 2011). Hence, integrating futures thinking, and business scanning approaches, such as analyzing megatrends, technological advancements, and intellectual property landscapes, is essential for enhancing an organization's ability to foresee and adapt to the dynamic business environment (Inayatullah, 2008; Miller, 2018b).

The research methodology for developing a comprehensive XaaS roadmap followed a rigorous multi-stage process, integrating the pulls of the future, the push of the present, and the weight of history through collaborative workshops. This approach aimed to systematically identify and validate potential business opportunities in the evolving XaaS landscape (Inayatullah, 2008).

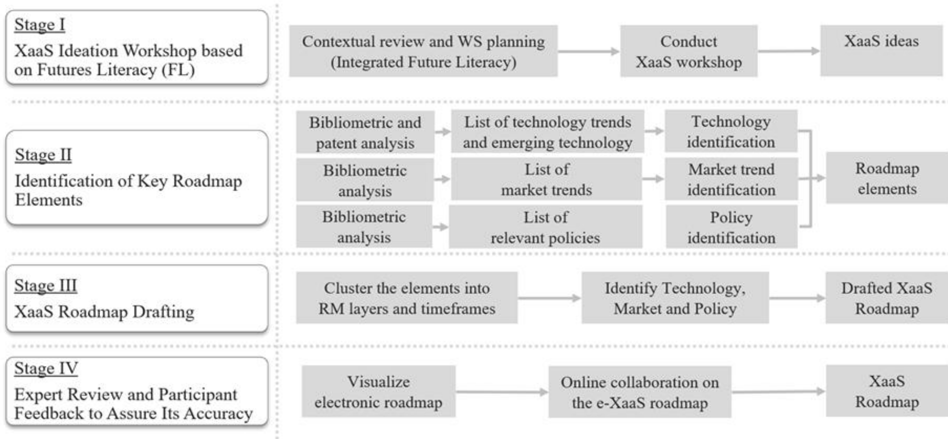

Figure 3.1 Knowledge co-creation workshop approach for XaaS Roadmapping

Source(s): Created by authors

3.2.1 Knowledge co-creation workshop

The design of the knowledge co-creation workshops is derived from a thorough examination of the current body of literature on XaaS and futures literacy techniques. The workshops foster a collaborative environment where participants leverage their collective ideas and insights to explore potential future business opportunities. This workshop empowers participants to develop a strategic roadmap that is responsive to market trends and proactive in anticipating future possibilities.

The workshop comprised four distinct stages, as depicted in Figure 3.1.

1) **Stage I: XaaS Ideation Workshop**

The strategy commences with Level 1 of FL, referred to as awareness, which aims to raise awareness regarding global warming and its potential impacts through a bilingual movie (JP/EN). The effort utilizes the concept of futures literacy (Miller, 2007, 2018a). Facilitators then motivate participants to envision the future world they desire to live in. The first stage of level 2 of FL, referred to as discovery, involves engaging to participate in guided activities that involve imagining the future and generating ideas. The approaches build upon service innovation tools for idea generation, including thinking aloud, speed thinking, and idea discussion (Hidalgo, 2020). During these activities, participants collaborate to generate a wide range of prospective XaaS business ideas. This stage also serves as an integral component of the socialization process, involving the sharing of thoughts and the exchange of ideas. The selection of ideas is based on four criteria that consider strategic aspects aligned with 1) Strategic aspects that align with decarbonization, consumer well-being and business strategy. 2) Desirability that meets customer needs is unique or is better than existing services. 3) Viability based on market size prospects and its future growth prospects. 4) The feasibility of ideas being implemented through technological/scientific development and potentially revolutionizing existing services has been explored in recent studies (Baldassarre et al., 2020; Ssegawa & Muzinda, 2021)

2) **Stage II: Identification of Key Roadmap Elements by Intelligence Activities**

This stage entails a thorough analysis of external elements that influence the development of XaaS. The workshop employs topic modeling to analyze patents and bibliometric data from Scopus journal articles, thereby addressing knowledge space limitations. This analysis involves identifying specific domains within the XaaS roadmap layer related to technical, policy, and market aspects. Participants actively verify these elements for inclusion in the XaaS roadmap and explicitly share knowledge through online surveys using Google Forms. This stage remains at level 2 of FL (discovery) and involves the externalization of acquired knowledge and shared experiences.

3) **Stage III: XaaS Roadmap Drafting**

This stage involves systematically imagining and organizing possible futures based on the verified elements from Stage II, resulting in a drafted XaaS roadmap. The elements, which include XaaS, technology, market trends, and policies, are categorized into layers. This stage continues at FL level 2 (discovery) and employs the combination process to map elements in its layer of roadmap utilizing available data.

4) **Stage IV: Expert Review and Participant Feedback to Assure Its Accuracy**

The final stage is to convert the drafted roadmap into a digital format. The collaborative functionalities of the Miro platform enable participants to actively modify and visualize the roadmap in real-time. Consequently, they are able to collaboratively refine the roadmap and cultivate a shared understanding. The validation of the XaaS roadmap occurs through expert review and feedback to ensure its accuracy, relevance, and feasibility. This stage, encompassing level 3 of FL (choice), provides new insights into the potential of the businesses. Participants have the chance to obtain the final XaaS roadmap, which will help them gain further understanding and develop their own new business or enhance existing strategies through the process of internalization (Murata et al., 2021).

3.3 Scenario-based Simulation

The research process involves developing plausible future scenarios based on expert opinions and a comprehensive literature review, considering various factors such as policy interventions, technological advancements, and consumer behavior. The system dynamics model then simulates the intricate interactions between these factors and their impact on CO_2 emissions over time. The model is parameterized using data from reliable sources and validated using historical data to ensure its accuracy and reliability. Additionally, sensitivity analysis is conducted to evaluate the robustness of the model and pinpoint the key drivers of change.

3.3.1 Scenario Analysis

Scenario development is an integral component of both technology roadmapping and service design. In the context of technology roadmapping, scenario-based approaches emphasize the analysis of non-technical influences, including market dynamics, societal trends, and economic factors. These factors are used to determine performance requirements and technological development pathways (Hussain et al., 2017). Similarly, scenario development in service design plays a crucial role in aligning service offerings with user expectations and adhering to legal and ethical guidelines (Imeri et al., 2016).

Considering the unpredictable and dynamic nature of the XaaS landscape, this study utilized a scenario-based approach to map out the future of XaaS. This approach entailed creating realistic future scenarios that considered a range of market trends, technological advancements, and regulatory changes. This enabled a thorough examination of possible opportunities and challenges. The scenario development process was guided by established frameworks (Hussain et al., 2017) and incorporated collaborative workshops with industry experts and stakeholders to ensure a holistic and multi-faceted perspective.

By integrating diverse scenarios into the XaaS roadmap framework, organizations can proactively formulate robust business strategies that are responsive to potential future occurrences. The XaaS roadmap, encompassing elements such as policy, market, service, and technology, provides a structured approach to addressing these situations. In order to encompass a wide range of possible consequences, scenarios are commonly categorized as either neutral, optimistic, or pessimistic (Geum et al., 2014).

The session enables participants to evaluate the likelihood of uncertainty for important aspects of the XaaS roadmap from different perspectives: neutral, optimistic, and pessimistic. The factors to consider include the implementation of regulations that support XaaS and sustainability, the growing social movement towards sustainability, the availability of funding and capital for core technology in XaaS, and the rate of adoption of these services by target consumers.

3.3.2 System Dynamics

3.3.2.1 Data Source

This study aims to assess the impact of Carbon Trading-as-a-Service (CTaaS) on the reduction of CO_2 emissions in Japan between 2030 and 2040, as outlined in its roadmap. Therefore, the model will utilize the CO_2 emissions and corresponding historical data from Japan. The data mainly comes from the government agency report.

3.3.2.2 System Dynamics Modeling

System Dynamics (SD) is a primary methodology for this study based on its abilities to visually represent systems with complex feedback loops and subsequently convert them into mathematical equations. System Dynamics is an analytical approach that examines the causal relationships and dynamic changes among different components within a complex system (Forrester, 2007a). This study reveals system variables for the XaaS roadmap that firms can utilize to formulate strategies.

The study employs a systematic approach, consisting of five distinct steps (Pérez-Pérez et al., 2021; Sternam, 2002; W. Zhang et al., 2021) which are detailed below.

1. Define the problem.
2. Determining the hypotheses and system boundaries by causal feedback loops.
3. Constructing mathematical models and stock-flow diagrams.

4. Testing the model's behavior.
5. Performing evaluations.

This study modifies and extends the existing model of personal carbon trading using Agent-Based Model, as proposed by Kothe et al. (2021). The model's attention shifts from analyzing agent behavior to examining the overall system structure to understand the potential consequences of the service innovation. The aim is to determine its results using system dynamics. The model commences with a fundamental model that comprises XaaS, policy, technology, and market, which is based on the structure of XaaS roadmap.

Chapter 4
XaaS Roadmapping Framework

4.1 Participants

The workshop was organized in collaboration with a Japanese non-profit organization representing engineering and social infrastructure sectors, alongside relevant stakeholders. The entire group comprises 257 enterprises as of June 2025. The organization's priorities are to decrease carbon emissions and establish a circular economy. These efforts aim to achieve the shared objective of protecting the environment and creating a prosperous society without competing mindsets. The workshop was attended by representatives from the business sector committees responsible for the development of new business opportunities. There are seven individuals representing prominent corporations in Japan. The participants are experts in their respective industries and have prior experience developing a smart infrastructure construction roadmap as shown in Table 4.1. This workshop intends to involve industry members to contribute significant expertise and insights into sector-specific challenges and opportunities, ensuring that collaboratively formed plans are grounded in practical realities.

While this workshop focuses on Japanese industry stakeholders, there is potential for applying the framework to other contexts. The workshop aims to reduce carbon emissions and implement a circular economy by involving industry members to contribute expertise and insights into sector-specific challenges and opportunities. This ensures that collaboratively formed plans are grounded in practical realities.

Table 4.1 Summary of Expert Profiles

Expert ID	Position / Role	Organization Type	Relevant Experience
EXP-01	Senior Manager	Global Engineering Company	Large-scale EPC projects in energy and infrastructure sectors
EXP-02	Expert	Major General Contractor in Japan	Design and construction in the energy sector
EXP-03	Section Chief	Comprehensive Engineering Company	Development of energy and environmental systems and infrastructure
EXP-04	Control & Instrumentation Engineer	Global EPC Specialist	Plant engineering for hydrocarbon and petrochemical industries
EXP-05	Expert	Leading General Contractor in Japan	Soil and environmental projects
EXP-06	Expert	Leading Japanese General Contractor and Engineering Firm	Building, civil engineering, and renewable energy projects
EXP-07	Lecturer & CEO	Academic & Technology Company	Business administration, innovation, and business development

4.2 Workshop and Results

A collaborative knowledge co-creation workshop was organized with researchers and an industrial organization specializing in social infrastructure. The workshop's focus was to envision and shape future service experiences that contribute to environmental sustainability, specifically targeting carbon emission reduction and circular economy principles. This initiative aligned with the shared goal of fostering a prosperous society while protecting the environment, shifting away from a competitive mindset. The challenge for participants, who were recognized experts in industry and technology roadmapping, was to explore how engineering and social infrastructure industries could contribute to a decarbonized society. Through a multi-step process designed to cultivate futures literacy and XaaS concept, participants engaged in a series of activities aimed at generating innovative service concepts that could drive sustainable change.

4.2.1 Stage I: XaaS Ideation Workshop

The workshop begins by presenting key concepts, such as futures literacy and XaaS, using a specifically created video clip that was available in both languages (EN/JP). Afterwards, we encouraged the participants to envision their ideal world in 2040, utilizing futures literacy strategies to stimulate their creative thinking. Participants actively participated in a brainstorming session to enhance their imaginative thinking. We used sticky notes for brainstorming to generate innovative service ideas aimed at fostering a shift in consumer attitudes towards carbon neutrality and enhancing customer wellbeing (Figure 4.1). Through a collaborative process of gathering and refining these ideas, we found a total of 14 potential service concepts. Each of these concepts has the ability to contribute to a future that is more environmentally conscious.

Table 4.2 Potential Service Ideas from Brainstorming Session provides a summary of the brainstorming sessions that produced fourteen possible service concepts. These concepts are based on five foundational pillars: environmental and energy (E), wellness (W), mobility Security (M), services within a virtual environment (V) and daily living (L). The proposed services encompass a wide range of offerings, including natural resource visualization and optimization service, customer experience for shifting ecological behavior, corporate carbon credit exchange service, household carbon credit exchange service, personal mental health service, physical health assistance service, health maintenance service, daily life information service, expected-value anticipation service, housework robot service, advanced luggage delivery service, advanced on-demand mobility service, metaverse in “second life”, virtual emotional well-being creation service (e.g., virtual onsen). Subsequently, each service concept's value proposition was defined.

We selected ideas for future services to create a prototype roadmap. The chosen ideas were developed further by establishing a value proposition and identifying a service value chain based on the XaaS concept. We selected service ideas from the concepts based on a multi-faceted evaluation. The evaluation result as shown in

We created ideas for future services in order to develop a prototype roadmap. The selected concepts were further developed by formulating a value proposition and outlining a service value chain using the XaaS concept. We employed the subsequent criteria to choose XaaS ideas: 1) Strategic aspects that must be compatible with a decarbonization society and business strategies. 2) Desirability that meets customer needs is unique or is better than existing services. 3) Viability based on prospects of market size and future market growth, and 4) Feasibility relying on confidence that ideas can be implemented in technological/scientific development and revolutionize existing services (Baldassarre et al., 2020; Ssegawa & Muzinda, 2021). To develop a prototype roadmap, we selected service ideas from the concepts based on a multi-faceted evaluation. This selection process prioritized the refinement of chosen ideas through the establishment of a clear value proposition and the identification of a service value chain aligned with the XaaS (Everything-as-a-Service) concept. The evaluation results as shown in Table 4.3 XaaS Ideas Prioritization.

The process of selection was influenced by the following criteria.

1. **Strategic Alignment**

Ideas were evaluated for compatibility with a society achieving decarbonization and broader commercial desires. This ensures that services actively contribute to environmental sustainability goals while aligning with the aims of the organization.

2. **Desirability**

The concept of desirability was assessed by considering its ability to fulfill client needs and its uniqueness in comparison to existing services, emphasizing generating innovative and customer-centric ideas.

3. **Viability**

The study assessed the practicality of each concept by examining its potential market size and future growth. The objective is to identify services with a promising market outlook and sustainable revenue generation capacity.

4. Feasibility

The study examined the viability of ideas in the context of technological and scientific advancements, focusing on concepts that demonstrated strong potential for successful execution and fundamental transformation of current service models.

Demonstration: Carbon credit trading-as-a-Service Roadmap

The workshop participants determined that the "E-4 Consumer carbon credit exchange service" was the most favorable idea. It was subsequently named "Carbon Credit Trading-as-a-Service" (CTaas) and was given to it afterwards, with the main purpose of enabling the trading of carbon credits from households. Figure 4.2 provided an overview of the service ecosystem for CTaas. It identified 10 additional service chains that might be delivered as XaaS, which serve as the basis for the XaaS roadmap and its service component.

The XaaS services identified within the CTaas value chain include:

S1: Match-buying as-a-service
S2: Carbon footprint as-a-service
S3: Carbon credits bank as-a-service
S4: Emission monitoring as-a-service
S5: Carbon swap as-a-service
S6: Carbon analytics as-a-service
S7: CCS (Carbon Capture and Storage) consultancy as-a-service
S8: CO_2 meter as-a-service
S9: Carbon neutrality investment fund as-a-service
S10: ITS (Intelligent Transport Systems) as-a-service

Table 4.2 Potential Service Ideas from Brainstorming Session

Future service ideas		Value Proposition
E-1	Natural resource visualization and optimization service	The natural environment will be virtually created for relaxation and to meet the expected needs.
E-2	Point service for shifting ecological behavior	The necessary advice for shifting behavior in accordance with ecological considerations will be delivered.
E-3	Corporate carbon credit exchange service	Corporate carbon credits are tradable
E-4	Consumer carbon credit exchange service	Household carbon credits are tradable
M-1	Advanced luggage delivery service	Intelligent automated luggage delivery without required process.
M-2	Advanced On-demand mobility service	Intelligent and pollution-free transportation on demand.
W-1	Personal mental health service	Mental health issues will be alleviated personally and comfortably with expertise.
W-2	Physical health assistance service (Human body)	A smart assistant monitors and advises on physical health maintenance.
W-3	Health maintenance service	Physical health issues will be treated with expertise and ease of access to services.
L-1	Daily life information service	The required information is delivered in a timely and full manner through synthesis of only the desired content and predictability of the necessary data.
L-2	Expected-value anticipation service	The desired value can be anticipated and delivered beyond expectation.
L-3	Housework robot service	Housework can be made easier with robot services. (For the elderly or when there is a shortage of labor.)
V-1	Metaverse in "second life"	A second real-life experience is created and securely interacts with the virtual environment.
V-2	Virtual emotional well-being creation service (e.g. virtual onsen)	Desired vacation destinations are presented in a virtual form to create emotional well-being whenever and wherever it is preferred.

Source(s): Created by authors

Table 4.3 XaaS Ideas Prioritization

	Criteria	Weight	XaaS Ideas													
			E-1	E-2	E-3	E-4	W-1	W-2	W-3	M-1	M-2	V-1	V-2	L-1	L-2	L-3
Strategy	Contribution to a decarbonized society	5	5	4.5	5	5	2.5	2.5	2.5	3.5	3.5	4	4	3.5	3.5	3.5
	Contribution to business	4	4	3.5	5	4.5	3.5	3.5	3.5	4	4	4	3	4	4	4
Desirability	Meets with the customer need	4.5	3.5	2.5	4	3.5	4	4	4	4	4	4	4	4	4.5	4.5
	Idea is unique or better than existing	3.5	3.5	3.5	3.5	3.5	3.5	4	4	4	4	3.5	3.5	4	4.5	4
Viability	Size of the market	4	4.5	4	4	4	4	4	4	4	4	4	4	3.5	4	4
	Growth of existing markets	4.5	3	3	4	4	4	4	4	4	4	4	4	4	4.5	4.5
Feasibility	Technical feasibility	3.5	4	4	4	4	4	4	3.5	4	3.5	4	4	3.5	3.5	3.5
Total			114.5	103.5	123.3	119	104.8	106.5	104.8	113.5	111.8	114.3	110.3	109.8	118	116.3

* 5: important, 4: not very important, 3: neutral, 2: not very important, 1: not important

Source(s): Created by authors

Source(s): Authors

Figure 4.1 XaaS Ideation Workshop

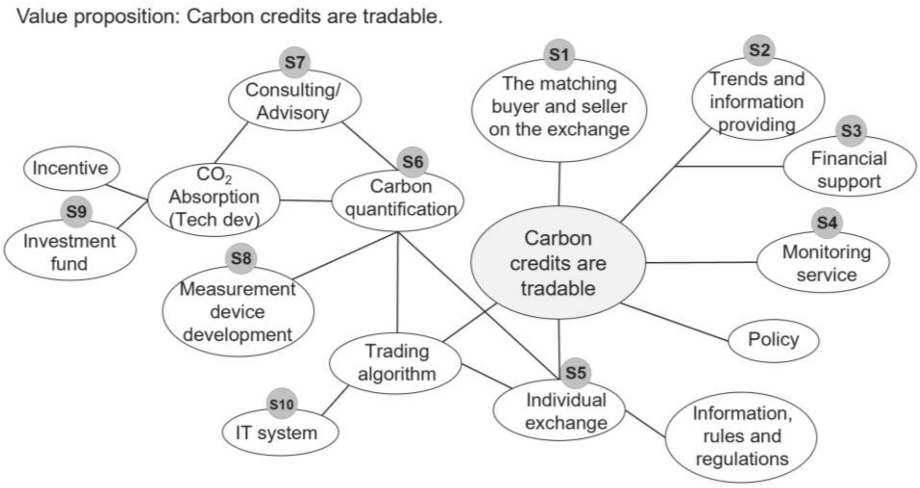

Figure 4.2 Initial concepts for the carbon credit trading-as-a-service chain

Source(s): Created by authors

4.2.2 Stage II: Identification of Key Roadmap Elements by Intelligence Activities

The selected XaaS ideas will be evaluated for prospective implementation timeframes (2022-2050), taking into account three key factors: market, technology, and policy, which influence the feasibility of their development. The data will be collected and organized from multiple sources to obtain supporting data relevant to the subject, encompassing market trends, advancements, and innovations in relevant technologies and policies. The data is obtained from patents and research publications, as indicated in Table 4.4 Sources of Key Roadmap Elements.

Table 4.4 Sources of Key Roadmap Elements

View	Database	Purpose
Policy	Publications	To discover relevant policies, regulations, or incentives globally.
Market	Publications	To identify market changes, relevant customer needs, and socioeconomic challenges.
Technology	Patents documents Publications	To recognize prospects by understanding technology advancement and emerging technology in global trends.

The process of gathering roadmap elements involves topic modeling and bibliometric analysis in RStudio, using the bibliometrics package on Scopus journal articles. This entails the identification of potential domains for technological advancements and other influential elements (Cobo et al., 2011; Aria & Cuccurullo, 2017). We conducted a Scopus search using specific keywords to find documents related to carbon credit trading and its relevance on the XaaS business value chain. We specifically focused on the connection between carbon credit trading and policy, market, and technology, respectively. Following that, we utilized RStudio 4.2.1 to syndicate author keywords and keywords plus from a large number of previously used, as well as emerging keywords, as depicted in Figure 4.3. The content was initially examined through abstract reading. These steps outline 25 essential elements for the roadmap.

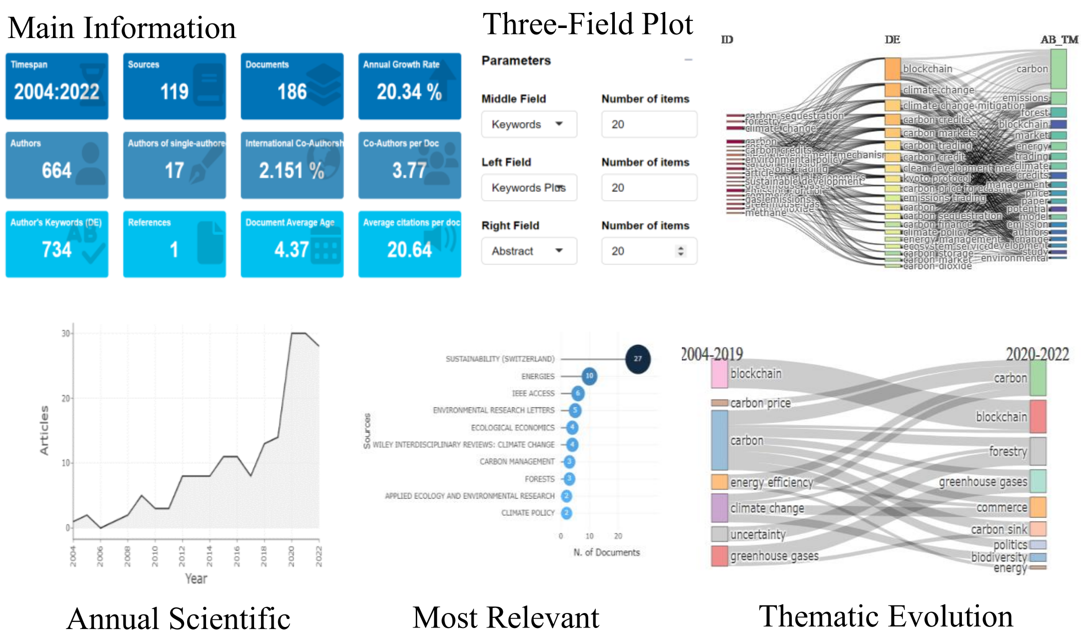

Figure 4.3 Bibliometric analysis using RStudio 4.2.1 to syndicate keywords

In addition, Technology Opportunity Discovery (TOD) using keyword-based patent analysis is a valuable method for leveraging the vast amount of information included inside patent documents (Feng et al., 2020). Through the examination of the frequency, co-occurrence, and interconnections of keywords derived from patent texts, researchers are able to identify emerging technological trends, white spaces, and potential areas for innovation. Several strategies have been proposed to enhance the effectiveness of keyword-based TOD. These include employing text mining techniques (Sungjoo Lee et al., 2009), combining semantic analysis (Wang et al., 2022; Seo, 2022), and applying machine learning algorithms (J. Lee et al., 2021). These approaches aim to address issues such as keyword ambiguity, synonyms, and the need to capture complex technological relationships. This study utilized advanced Derwent innovation in patent analysis to extract the keywords associated with technology layer elements using Boolean operators. Carbon credit ‘AND' Trading ‘AND' Technology ‘OR' Infrastructure are the keywords. The insights provide us with the relevant keywords. The content was initially examined through abstract reading. The patent dataset used in this study has been updated with patent information published between 2012-2022. The data collection results consist of 164 individual records within 123 DWPI families, encompassing 138 application numbers. The top technologies in this space are G06F electric digital data processing and G06Q data processing systems or methods. The top technology trends identified by a keyword search of carbon credit trading and its technology relevance to the XaaS business value chain from 2012-2022 include blockchain, transaction, payment, inventory, asset, cloud, and computing, as depicted in Figure 4.4.

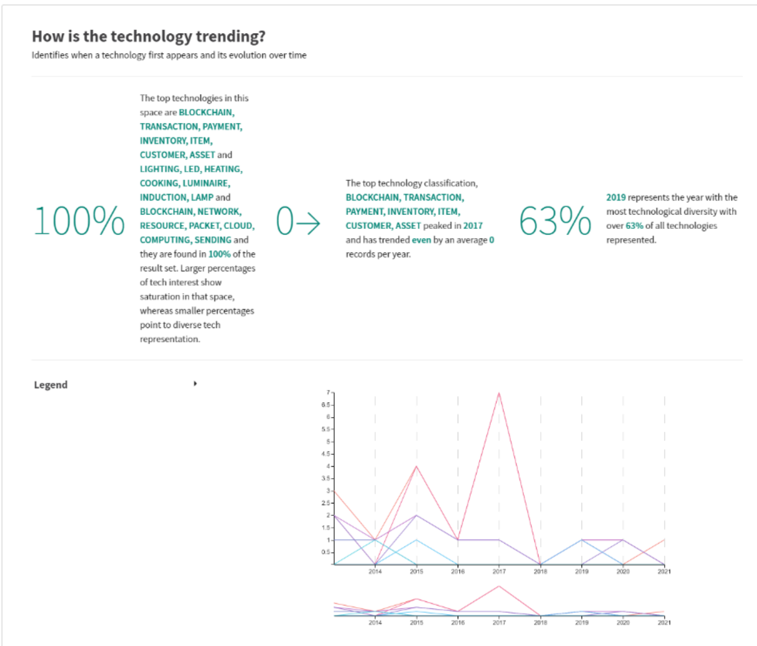

Figure 4.4 Patent analysis for CTaaS using Derwent innovation

This study leverages the structure of the service roadmap to guide creating the XaaS roadmap (Cho & Lee, 2014; Suh & Park, 2009; Wells et al., 2004).

1) The service layer focuses on the core service offering, which includes design, development, delivery, and management. It entails identifying the service's value proposition, target segments, and differentiating features.
2) The market layer analyzes customer demands, preferences, and behaviors through market research, competition analysis, and trend forecasts.
3) The technology layer defines the technological infrastructure and capabilities needed to support the service, such as software platforms, hardware requirements, data management, and cybersecurity, assuring the service's technological viability and durability.
4) The policy layer handles the legal and regulatory context in which the service operates, ensuring adherence to industry norms and data privacy regulations.

The combination of these layers allows for a comprehensive understanding of the service landscape, allowing companies to align their services with market trends, technology capabilities, and regulatory requirements (Menor & Roth, enabling firms to match their services 2007). This encourages cross-functional collaboration and communication, resulting in a shared understanding of the service vision and strategy among all stakeholders (Huang et al., 2018; Kim & Geum, 2021).

To determine the elements for validation, we consolidated all the keywords and initial assessments, as displayed in Table 4.5. We have formulated an extensive strategy for the period from 2023 to 2050 to illustrate the roadmap for XaaS. This roadmap incorporates key factors such as policy, market trends, XaaS solutions, and technology to provide a clear visualization of CTaaS. It highlights the interdependencies among various components, as depicted in Figure 4.5. Following that, a survey was created to gather the viewpoints of participants through a Google form, with the purpose of confirming each component and establishing the suitable duration between 2023 and 2050, based on the participants' individual experiences and perceptions. During these stages, participants will have the opportunity to carefully examine supplementary information and provide any relevant extra details.

Table 4.5 The Initial Roadmap Elements with Description

XaaS RM Layers	Key Roadmap Elements	Description
Policy	Paris Agreement	Emissions need to be reduced by 45% by 2030 and reach net zero by 2050.
	Net-zero GHG emissions by 2050	The Japanese government has declared that it will achieve carbon neutrality by 2050.
	Strategic Energy Plan to 2030	The theme of the strategy is to chart a path to carbon neutrality by 2050.
	Emissions Trading Scheme (ETS)	Japan plans to create its first domestic carbon emissions trading market, with a demonstration project to begin in September 2022.
	Society 5.0	A human-centered society that achieves both economic development and the resolution of social problems through a system that highly integrates cyber and physical spaces.
	RE100: 100% Renewable Energy	A carbon-free social policy that utilizes renewable energy in Kaga City and aims to revitalize the local economy through the ecosystem.
	Smart City	A next-generation city that realizes a society that integrates AI, IoT, and robotics.
Market	Biodiversity /regeneration	Biodiversity refers to the vast variety of life forms on Earth, and restoration is how various human exploitation practices contribute to the natural processes that occur in ecosystems, such as absorbing carbon and regulating the climate.
	Sustainability/Eco-Consumption	Purchasing and using products that have a lower environmental impact.
	VR/AR/MR/XR	Virtual Reality (VR) Augmented Reality (AR) Mixed Reality (MR) Extended Reality (XR)
	Metaverse	A unified digital platform centered around virtual reality and augmented reality.
	Crypto commerce/NFT	It is an e-commerce platform that uses blockchain and cryptocurrency.
	Super apps	A mobile application that is self-service oriented and provides a set of personal and commercial services (e.g., Paypay).
XaaS	Carbon credit exchange-as-a-Service	A service that allows customers to exchange carbon credits.
	Digital Carbon Footprint-as-a-Service	A service that allows consumers to easily calculate how much carbon is being generated in various activities in human society.
	Carbon farming-as-a-Service	Consulting services to advance business activities to optimize carbon capture in natural ecosystems.
	Emission monitoring-as-a-Service	Services that investigate and report on the trends and impacts of pollution caused by various activities.
	Carbon data-as-a-Service	A service that supports the collection of carbon emission-related information.
	Smart contract-as-a-Service	A self-contained contract in which the contractual details between the buyer and seller are recorded on the blockchain.
	Payment-as-a-Service	A service that provides online payments.
	Finance-as-a-Service	Providing financial services such as fundraising, tax planning, and investment advice.
	Consultancy-as-a-Service	Expert guidance on carbon emissions, including carbon reduction, carbon trading, laws, and regulations.
	Data analytics-as-a-Service	Carbon and energy data analysis advisory services to evaluate and consider carbon emissions and energy usage.
	IT-as-a-Service	A service that proposes IT solutions that contribute to improving energy efficiency.
Technology	Secure trading platform	The application of blockchain architecture enables cyber-secure communication, protecting the integrity, authenticity, auditability, and consistency of all transactions, and eliminating issues of transaction fees, scalability, and latency.
	Carbon Emissions Measurement and Data System	A platform for measuring and analyzing greenhouse gas emissions and carbon footprints on an asset-by-asset basis.
	Emissions Data System	A platform that uses existing data on carbon emissions to measure and analyze greenhouse gas emissions and carbon footprints at the asset level, including estimating specific emissions over time
	Microgrid	An energy system that serves a specific geographic area, can use multiple renewable sources, and is controlled by a software-based system.
	Blockchain	It is a decentralized ledger of all transactions across a peer-to-peer network to confirm transactions without the need for a central clearing house.
	Carbon price forecast	Carbon credit trading price prediction using machine learning.
	Carbon price dynamics	Calculating the cost of carbon credits in real-time pricing using machine learning.
	Carbon capture and storage	Carbon capture and storage technologies.
	Carbon measuring device	Example : Soil carbon measurement

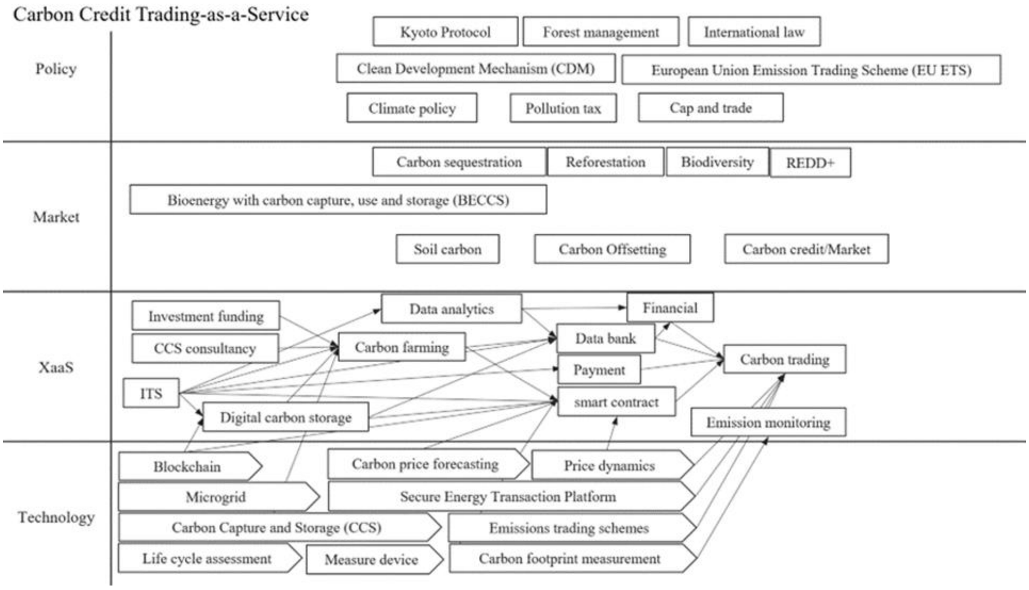

Figure 4.5 Stage II Carbon credit trading-as-a-Service Roadmap
Source(s): Created by authors

This study leverages the structure of the service roadmap to guide creating the XaaS roadmap (Cho & Lee, 2014; Suh & Park, 2009; Wells et al., 2004).

1) The service layer focuses on the core service offering, which includes design, development, delivery, and management. It entails identifying the service's value proposition, target segments, and differentiating features.
2) The market layer analyzes customer demands, preferences, and behaviors through market research, competition analysis, and trend forecasts.
3) The technology layer defines the technological infrastructure and capabilities needed to support the service, such as software platforms, hardware requirements, data management, and cybersecurity, assuring the service's technological viability and durability.
4) The policy layer manages the legal and regulatory framework under which the service functions, guaranteeing compliance with industry standards.

The combination of these layers allows for a comprehensive understanding of the service landscape, allowing companies to align their services with market trends, technology capabilities, and regulatory requirements (Menor & Roth, enabling firms to match their services 2007). This encourages cross-functional collaboration and communication, resulting in a shared understanding of the service vision and strategy among all stakeholders (Huang et al., 2018; Kim & Geum, 2021).

4.2.3 Stage III: XaaS Roadmap Drafting

After gathering responds to the surveys, which examined each element and included additional comments, certain elements were found to be less significant while additional issues were introduced, each with their respective time frames. Given that this is an individual point of view, opinions may vary for each individual element. We created a second roadmap through enhancing the structure of responses and employing color intensity levels to visually indicate the frequency of individuals' responses to the feedback within a reasonable time period, as depicted in Figure 4.6. The revised XaaS roadmap will be reformed into a digital format to facilitate collaboration throughout Stage IV: Expert Review and Participant Feedback to Assure Its Accuracy.

The Miro board illustrates a co-creation roadmap for XaaS, spanning from 2023 to 2050, created by industry experts. The process utilized Miro's collaboration features to facilitate this complex endeavor.

The roadmap is segmented into multiple layers: Policy, Market, XaaS, and Technology, which encompasses Application/Platform, Software, and Hardware. Each layer symbolizes a distinct aspect of the XaaS ecosystem. The roadmap is subdivided into distinct time periods: 2023-2025, 2026-2030, 2031-2040, and 2041-2050. This separation enables a strategic approach to long-term planning and development. Sticky notes are used to indicate specific details and are placed in their corresponding themes and timeframes. Arrows and lines are used to visually connect related items, illustrating dependencies, sequences, or the evolution of specific ideas over time. The selection of color codes was based on the individual choices made by participants. However, it is important to note that these color codes do not carry substantial meaning in terms of indicating elements such as priority, status, or category of the initiative. Figure 4.7 displays the entire visualization.

The Miro board demonstrates how collaborative online platforms can be utilized to collectively develop complex roadmaps, especially in the constantly evolving XaaS landscape. The approach facilitated a collective comprehension among the experts, leading to a thorough, easily understandable, and implementable strategy for the development of XaaS over a period.

Figure 4.6 Stage III Carbon credit trading-as-a-Service Roadmap

Source(s): Created by authors

Figure 4.7 An Electronic XaaS roadmap by expert brainstorming (Miro)

Source(s): Created by authors

4.2.4 Stage IV: Expert Review and Participant Feedback to Assure Its Accuracy

Industry experts collaborated online using the Miro platform to review and develop a digital XaaS roadmap. The roadmap covers the period from 2023 to 2050. The process employed Miro's collaborative features to facilitate this complex endeavor. The roadmap is segmented into multiple layers: Policy, Market, XaaS, and Technology. Each layer represents a distinct aspect of the XaaS ecosystem. The roadmap is subdivided into distinct time periods: 2023-2025, 2026-2030, 2031-2040, and 2041-2050. This division allows for a strategic approach to long-term planning and development.

This section facilitates a systematic approach to the formulation and execution of long-term plans and the advancement of projects. Figure 4.8 presents the final XaaS roadmap, which can be summarized as Table 4.6 Strategic target of XaaS roadmap. The XaaS roadmap is validated through participant review and feedback to ensure its accuracy, relevance, and feasibility. In addition to assessing the possible development timeframe for each XaaS business based on its ecosystem, participants also considered each step to determine a timeline for business development. Finally, participants can obtain a complete XaaS roadmap to deepen their comprehension and create their own new business or enhance the existing strategy.

The XaaS roadmap outlines the evolution of specific service offerings within the Carbon Credit Trading-as-a-Service (CTaaS) ecosystem across different timeframes. The details for each phase are outlined as follows:

Phase I (2023-2025) The Foundation Phase: The initial phase focuses on establishing the foundational XaaS offerings that will support the CTaaS ecosystem. This period sees the introduction of **Digital Carbon Footprint-as-a-Service**, which could involve services that calculate and track the carbon footprint of digital activities, and **Carbon Data-as-a-Service**, involves the collection, processing, and analysis of carbon data, which is crucial for monitoring and managing carbon emissions.

Phase II (2026-2030) The Expansion Phase: This phase aims to expand the range of XaaS offerings and enhance their functionality and accessibility. The emphasis shifts to Consultancy-as-a-Service, Emissions monitoring-as-a-Service, Carbon

Analytics-as-a-Service, IT-as-a-Service, Finance-as-a-Service, and Payment-as-a-Service. **Consultancy-as-a-Service** refers to providing expert advice as a service, likely related to achieving carbon neutrality. **Emissions monitoring-as-a-Service** involves services that monitor and report on greenhouse gas emissions. The emphasis in **Carbon Analytics-as-a-Service** is on developing advanced analytics tools and services to help businesses and individuals gain deeper insights into their carbon emissions data and identify opportunities for further reduction. **Finance-as-a-Service** provides financial services such as fundraising, tax planning, and investment advice related to carbon credit trading and decarbonization initiatives. **IT-as-a-Service** and **Payment-as-a-Service** refer to the provision of IT and payment services, respectively, on an as-needed basis.

Phase III (2031-2040) The Integration and Optimization Phase: This phase focuses on further integrating and optimizing the various XaaS offerings within the CTaaS ecosystem. This period sees the introduction of **Carbon Credit Trading-as-a-Service**, a digital platform or solution that facilitates the buying and selling of carbon credits. These credits represent a reduction or removal of greenhouse gas emissions from the atmosphere, usually measured in metric tons of carbon dioxide equivalent (CO_2^e). It also includes **Carbon Farming-as-a-Service**, a service model where farmers are assisted and supported in implementing carbon farming practices on their land, and **Smart Contract-as-a-Service**, providing smart contract solutions to automate and streamline various aspects of carbon credit trading, such as agreement execution, compliance monitoring, and payment processing.

Phase IV (2041-2050) The Maturity and Sustainability Phase: The final phase aims to achieve a mature and sustainable CTaaS ecosystem that effectively supports the transition to a decarbonized society. The focus is on continuous improvement, innovation, and adaptation to new challenges and opportunities.

The XaaS roadmap demonstrates a strategic and phased approach to developing a comprehensive CTaaS ecosystem. By leveraging futures literacy and knowledge co-creation, the roadmap anticipates future trends and challenges, ensuring that the XaaS offerings remain relevant and effective in supporting the transition to a decarbonized society.

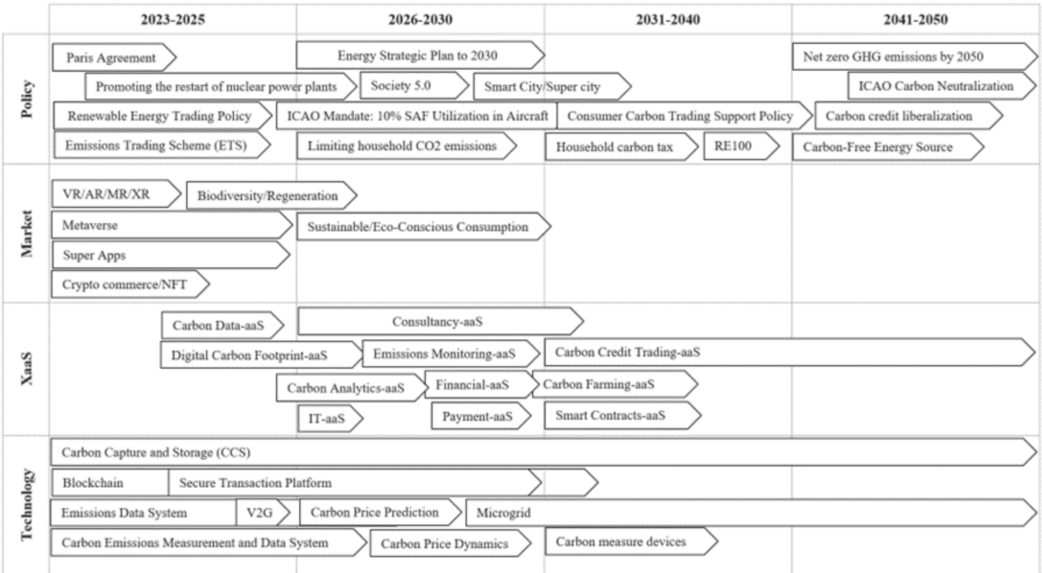

Figure 4.8 Stage IV Carbon Credit Trading-as-a-Service Roadmap

Source(s): Created by authors

Table 4.6 Strategic target of XaaS roadmap

Phase	I	II	III	IV
T\imeframe	2023-2025	2026-2030	2031-2040	2041-2050
Target	Promote renewable energy	Enhance energy efficiency	Develop carbon capture and storage technologies	Achieve net-zero carbon emissions
XaaS launching	Carbon Data-as-a-Service, Digital Carbon Footprint-as-a-Service	Consultancy-as-a-Service, Emissions Monitoring-as-a-Service, Carbon Analytics-as-a-Service, IT-as-a-Service, Financial-as-a-Service, Payment-as-a-Service	Carbon Credit Trading-as-a-Service, Carbon-Farming-as-a-Service, Smart Contracts-as-a-Service	Enhance the service system
Area for technology development	Develop blockchain technology, a secure trading platform, and a carbon emissions data system.	Continue to enhance emissions data systems and investigate the potential for incorporating microgrids.	Further leverage blockchain technology and develop advanced models for carbon price forecasting and dynamics.	Continue developing carbon capture and storage technology and carbon measuring devices.

Source(s): Created by authors

4.3 Evaluation

The evaluation of the knowledge-based service innovation workshop was grounded in established theories and frameworks from the fields of workshop evaluation. Specifically, the evaluation strategy drew upon the Participant Satisfaction Questionnaire (PSQ) framework (Lewis & Lewis, 2006) to assess participants' perceptions of the workshop's design, process effectiveness, and perceived outcomes. The PSQ aligns with the broader literature on workshop evaluation, which emphasizes the importance of gathering feedback from participants to assess the success of a workshop and identify areas for improvement (Abdulghani et al., 2014; Black & Earnest, 2009; Skivington et al., 2021). Prior research has demonstrated the PSQ's reliability and validity in measuring participant satisfaction and perceived learning outcomes (Hammond et al., 2003). By capturing participants' perspectives on various aspects of the workshop, the PSQ provides valuable insights into the strengths and weaknesses of the workshop design, content relevance, facilitation effectiveness, and overall satisfaction. This information can be used to inform people about the design and delivery of future workshops, ensuring that they are more engaging, effective, and impactful.

To further enrich the evaluation, open-ended questions were incorporated into the survey to provide participants with the opportunity to elaborate on their experiences and offer nuanced feedback. This approach acknowledges that while quantitative measures like the PSQ offer valuable insights, they may not capture the full complexity of participant experiences (Thomas, 2006). Open-ended questions allow for a more in-depth exploration of participants' thoughts and feelings, potentially revealing unexpected findings and areas for improvement.

Furthermore, the use of qualitative data analysis techniques, such as thematic analysis and constant comparison (Braun & Clarke, 2008), allowed for a deeper exploration of participant experiences and the underlying reasons behind their satisfaction or dissatisfaction with the workshop. This approach aligns with the principles of stakeholder engagement in strategic planning processes, which emphasize the importance of incorporating diverse perspectives to ensure the relevance and effectiveness of strategic initiatives (Brugha & Varvasovszky, 2000). Organizations can gain a more thorough understanding of the workshop's impact and pinpoint areas for improvement that may not be visible through quantitative measures by actively involving stakeholders in the evaluation process.

A custom survey tool was developed to evaluate participant perspectives from a knowledge-based service innovation workshop. The tool used the Participant Satisfaction Questionnaire (PSQ) (Lewis & Lewis, 2006) to evaluate workshop design, process effectiveness, and perceived outcomes (Healey et al., 2015). Qualitative data analysis, employing thematic analysis and constant comparison techniques (Braun & Clarke, 2008), was used to categorize and interpret participant feedback. This approach emphasizes the importance of incorporating diverse perspectives for future workshops' effectiveness.

The study evaluated the effectiveness of a knowledge co-creation workshop for XaaS roadmapping by distributing a questionnaire to all participants. The study consisted of seven business experts who were members of the subcommittee and possessed expertise in their respective fields of business. Additionally, they had prior experience participating in technology roadmapping. The survey was derived from three perspectives: the process, activities, and results. The questions were pre-coded and open-ended, using a five-point Likert scale. Statistical processing was conducted to examine satisfaction, as detailed in Table 4.7.

The findings reveal a generally positive response to the XaaS roadmap process, with mean values for most factors exceeding 4 on a 5-point scale. The integration of futures literacy (1-1) is rated highest, with a mean value of 4.714 and the lowest standard deviation (0.488). This highlights the importance of futures literacy in creating an efficient and innovative XaaS roadmap. This highlights the significance of futures literacy in directing the creation of an efficient and innovative XaaS roadmap. However, the result received the lowest average rating (3.857) and the highest standard deviation (0.690). This indicates that there was a broader range of participant opinions and a relatively lower degree of overall satisfaction with this specific aspect of the roadmap process.

Table 4.7 Description Descriptive Statistics of Questionnaire Responses

No	Variable	Mean	SD	95% CI		Minimum value	Maximum value
				Lower limit	Upper limit		
1	(1-1) Process: Futures literacy integration	4.714	0.488	4.474	4.954	4	5
2	(1-2) Process: XaaS ideation	4.286	0.488	4.046	4.526	4	5
3	(1-3) Process: Roadmap elements identification	4.429	0.535	3.512	4.488	4	5
4	(1-4) Process: e-Roadmap collaboration	4.286	0.488	4.165	4.693	4	5
5	(2-1) Workshop activities: Overall	4.000	0.577	4.046	4.526	3	5
6	(2-2) Workshop activities: Validating RM element using Google Forms	4.000	0.816	3.718	4.282	3	5
7	(2-3) Workshop activities: Miro-based electronic XaaS roadmap	4.286	0.488	3.602	4.398	4	5
8	(3) Result	3.857	0.690	4.046	4.526	3	5

Source(s): Created by authors

The XaaS Roadmapping workshop was evaluated based on participant feedback, revealing several strengths and positive outcomes. The workshop's emphasis on future visioning fostered creativity and strategic thinking, aligning with future thinking and foresight (Gabriel, 2014). The focus on imagining "the society you want to live in" resonated with participants, echoing studies that emphasize the importance of a shared vision in driving innovation (Amabile et al., 1996). The collaborative nature of the workshop, despite participants' diverse backgrounds, resulted in a comprehensive and nuanced outcome. The use of scenario planning, incorporating both optimistic and pessimistic views, proved effective in understanding the potential impact of various drivers and enablers. Participants found this approach helpful in identifying potential risks and opportunities, leading to a more robust roadmap. The step-by-step approach to thinking encouraged focus and multiple perspectives, aligning with research on decision-making frameworks.

An identified weakness was the lack of an initial overview of the entire process. Participants suggested a video or presentation at the beginning of the workshop to provide context and better understand the workshop's objectives. The use of online collaboration tools like Miro raised concerns about compatibility with enterprise security regulations. This finding highlights the need for organizations to carefully evaluate the security implications of using online collaboration tools before incorporating them into workshops. Overall, the workshop provided valuable insights into the workshop approach and the concrete results achieved through participant collaboration.

4.4 Results and Discussion

The XaaS roadmapping workshop was found to be effective in strategic planning and collaboration among industry experts. It highlighted the importance of considering city size, incorporating online collaboration technologies, and scenario expression for decision-making. Key strengths included future visioning, scenario planning, and a step-by-step approach. The workshop also incorporated diverse perspectives and online collaboration technologies. However, opportunities for improvements include providing an initial overview of the process and addressing concerns about compatibility with enterprise security regulations.

Future research should explore workshop methodologies and other factors influencing roadmap development. Improving the workshop includes an introductory process overview, secure online collaboration platforms, tailoring roadmaps based on city size, and integrating scenario-based activities. Consistent participant input is crucial for continuous improvement.

4.5 Conclusion

The XaaS roadmap, validated through participant feedback, provides a strategic and phased approach to developing a comprehensive Carbon Credit Trading-as-a-Service (CTaaS) ecosystem. The roadmap, built on the principles of futures literacy and knowledge co-creation, anticipates future trends and challenges. This ensures that XaaS offerings are relevant and effective in facilitating the shift towards a decarbonized society. The integration of scenario-based analysis was also recommended to further enhance decision-making processes and strategic planning. The use of online collaboration tools has advantages in terms of communication and collaboration. There are concerns about compatibility with enterprise security regulations. This highlights the importance of carefully considering the security implications when integrating these tools. The insights gained from this evaluation can guide the development and execution of future XaaS roadmapping workshops, enhancing the efficiency of strategic planning and cooperation in the ever-changing technological environments. By addressing the identified areas for improvement and incorporating feedback from participants, future workshops can be enhanced to have a greater impact and contribute to the development and implementation of XaaS solutions in different situations.

The study's findings indicate that including Futures Literacy into the XaaS roadmapping framework enhances the strategic vision of businesses transitioning towards sustainable service models. The results reflect the initial hypothesis that FL fosters innovative value chains, especially in carbon credit trading services. Although FL is a valuable concept for strategic planning, its effectiveness depends on external factors such as regulatory frameworks and market readiness.

Chapter 5
Scenario-based Simulation

5.1 Scenario Analysis

We developed the XaaS Roadmap for CTaaS by considering three scenarios: neutral, optimistic, and pessimistic. Each scenario considers different assumptions about policy interventions, technological advancements, and consumer behavior, allowing for a comprehensive assessment of the potential impact of CTaaS on household carbon reduction.

The **neutral scenario** sees moderate technological advancement in XaaS businesses due to a lack of targeted policy support and limited social pressure for decarbonized consumption. The adoption rate follows typical patterns, with funding and resources for essential technologies remaining stable, aligning with the market's steady growth trajectory.

The **optimistic scenario** sees rapid growth and technological advancements in the XaaS industry due to a supportive policy environment and strong public advocacy. A growing social movement towards sustainability further accelerates XaaS adoption, surpassing the neutral scenario. Investments are strategically directed towards key technologies that create synergistic value with other XaaS offerings, promoting collaboration and comprehensive solutions.

The **pessimistic scenario** presents a challenging landscape for XaaS businesses due to insufficient government backing and limited public awareness of sustainability issues. The low adoption rate and slow technological advancement are exacerbated by the need for substantial investments to establish a foundational XaaS ecosystem exacerbating the low adoption rate and slow technological advancement, as the absence of existing offerings necessitates higher upfront costs.

The specific assumptions underlying the scenarios employed in this study are detailed in Table 5.1. The integration of scenario development into XaaS roadmapping allows organizations to proactively identify emerging opportunities and challenges, develop adaptable strategies, and create greater value for users and stakeholders. This is particularly important in the context of XaaS, where rapid technological change and evolving customer expectations necessitate a forward-looking and responsive approach to service innovation.

Table 5.1 Scenario of Carbon Credit Trading-as-a-Service

Year	Scenario	Policy Layer	Market Layer	XaaS Layer	Technology Layer
2026-2030	Optimistic	Ambitious renewable energy targets and carbon pricing, widespread adoption of Society 5.0 principles.	Increasing consumer demand for sustainable products and services, growing interest in biodiversity and regeneration.	Widespread adoption of Emission Monitoring-as-a-Service, Financial-as-a-Service, etc., lead to efficient and transparent carbon credit trading.	Mature and integrated emissions data systems, microgrids, and blockchain technology.
	Neutral	Moderate progress on renewable energy targets and carbon pricing, Society 5.0 faces implementation challenges.	XaaS market growth is steady, but growth is limited by price sensitivity and uncertainties.	XaaS use rising, but complexity and cost concerns remain.	Advancements in emissions data systems, microgrids, and blockchain continue, but integration and scalability remain issues.
	Pessimistic	Policy implementation stalls, limited progress on renewable energy and carbon pricing, resistance to Society 5.0.	A decline XaaS market, limited consumer interest, and lack of financial incenti ves for businesses.	XaaS adoption is slow, organizations and individuals prefer traditional methods.	Slow technological advancements and integration challenges hinder the development of CTaaS ecosystem.

Table 5.1 Scenario of Carbon Credit Trading-as-a-Service *(Continued)*

Year	Scenario	Policy Layer	Market Layer	XaaS Layer	Technology Layer
2031-2040	Optimistic	Strengthening carbon emission regulations and incentives while promoting smart city initiatives. There is a policy that supports the advancement of XaaS for a decarbonized society.	Rapid growth in the XaaS market due to favorable policies and public promotion, alongside a growing social movement towards sustainability.	The CTaaS ecosystem is mature, optimized for seamless integration, with significant investments in carbon neutrality initiatives. XaaS businesses collaborate to provide comprehensive customer solutions.	Rapid technological advancements, including blockchain and advanced carbon price forecasting and dynamics models, enable proactive risk management and XaaS offerings.
	Neutral	The implementation of regulations and incentives to reduce carbon emissions is ongoing, along with advancements in smart city initiatives, but no specific policy is in place for XaaS.	Moderate growth in the XaaS market, with typical pattern of adopting XaaS and restricted social movements for decarbonized consumption transition.	The CTaaS ecosystem expands, but integration and optimization face hurdles, increasing adoption, but some remain cautious.	Moderate pace of technological advancement in XaaS businesses, with consistent funding and resources for essential technologies.
	Pessimistic	The policy advancement process has stalled due to insufficient enforcement and a lack of new incentives. Failure to establish XaaS policy and decarbonization.	Slower adoption in the XaaS market due to limited consumer interest and lack of attention to sustainability concerns.	CTaaS ecosystem struggles, limited adoption of new offerings, challenges in maintaining existing services.	The lack of an established XaaS ecosystem is hindering development due to slow technological advancements and requiring substantial investments.

Source(s): Created by authors

5.2 System Dynamics

The purpose of the system dynamics model is to assess the impact of Carbon Trading-as-a-Service (CTaaS) on CO_2 emissions in Japan from 2030 to 2040, as outlined in its roadmap. The model incorporates factors such as technological advancement, policy responses, and social movement strength to study the scenarios. The analysis includes sensitivity and scenario simulations to understand the model's behavior under varying conditions. The simulation results have been detailed across three different scenarios, including neutral, optimistic, and pessimistic.

5.2.1 Case Demonstration

The growing concern over climate change has led to a greater interest in individual carbon emission reduction strategies. Residential energy consumption accounts for twenty percent of global energy consumption, excluding fuel consumption. From 1990 to 2017, Japanese household energy consumption increased by 42.0%. This includes space heating, space cooling, water heating, cooking, lighting, and appliances (Arimura & Matsumoto, 2020). Household carbon credit trading is a mechanism that allows households to engage in the buying and selling of carbon credits to offset their emissions. Individuals can purchase carbon credits from households or businesses that have reduced their emissions below a certain limit. Conversely, households that lower their emissions below the established level can trade carbon credits with other households or companies that are unable to meet the established level (Brr & Nordstrr, 2004). Household carbon credit trading operates by establishing a benchmark for carbon emissions based on the average emissions of a particular region or population. The earnings from carbon credits trading can be allocated towards funding further sustainability initiatives (Asakawa et al., 2021).

5.2.2 System Dynamics Modeling

The System dynamics model can be used to construct causal relationships between key CO_2 emission factors based on a mathematical model. The SD model was built and run on the Vensim® PLE version 10.2.1, as illustrated in Figure 5.1 and

Figure **5.2**. The causal loop diagram represents the complex dynamics of carbon emissions, carbon credits, and the adoption of Carbon Credit Trading as a Service (CTaaS). The model captures a dynamic system where various elements interact, creating feedback loops that impact carbon emissions and the effectiveness of the carbon credit trading mechanism.

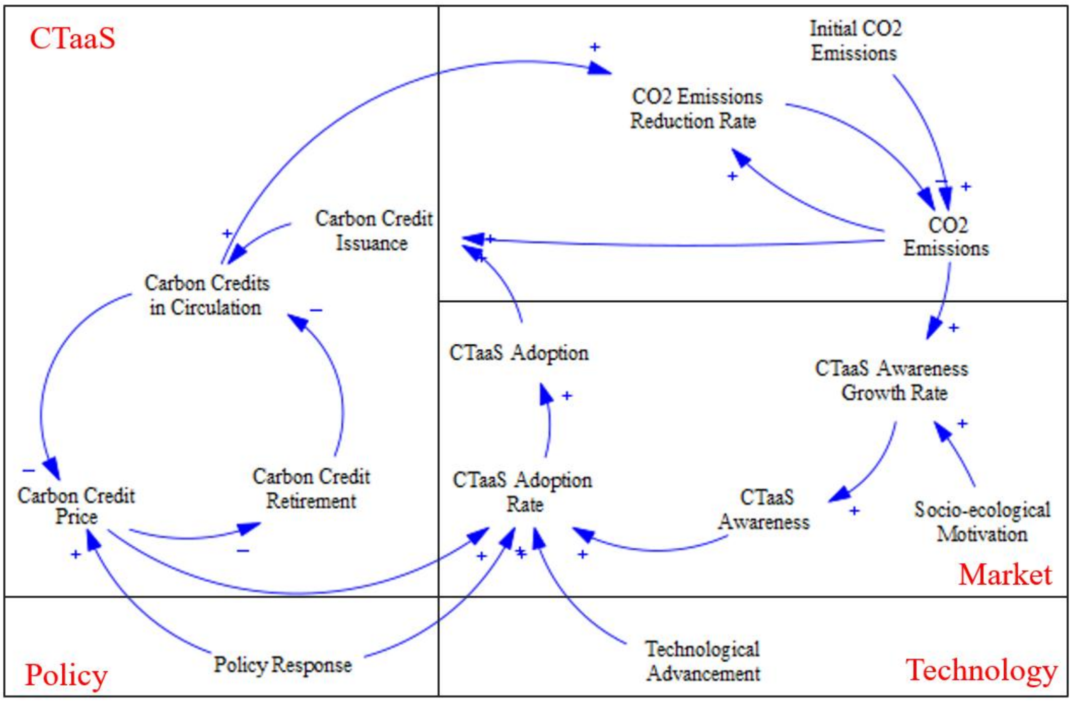

Figure 5.1 Causal loop diagram of the CTaaS roadmap

Source(s): Created by authors

Key causal loops in the CTaaS models are as follows.

Balancing Loop: CTaaS Adoption and CO_2 Emissions Reduction.

This loop demonstrates how CTaaS adoption can create a positive feedback loop, driving down CO_2 emissions. This loop illustrates the core mechanism by which CTaaS contributes to CO_2 emission reduction.

1) **CO_2 Emissions and Reduction Loop**

This loop represents a balancing feedback loop where increased emissions lead to efforts to reduce them, eventually bringing emissions back down.

Initial CO_2 Emissions → (+) CO_2 Emissions: The system starts with an initial level of CO_2 emissions.

CO_2 Emissions → (-) CO_2 Emissions Reduction Rate: Higher CO_2 emissions can trigger efforts to reduce emissions, leading to an increased reduction rate.

CO_2 Emissions Reduction Rate → (-) CO_2 Emissions: A higher reduction rate leads to a decrease in overall CO_2 emissions.

2) **Loop 2: Carbon Credits and Emissions loop**

This loop demonstrates a balancing feedback mechanism. Increased emissions lead to more carbon credits, which can lower their price and reduce retirement, eventually influencing the number of credits in circulation.

CO_2 Emissions → (+) Carbon Credit Issuance: Higher CO_2 emissions trigger the issuance of more carbon credits to offset pollution.

Carbon Credit Issuance → (+) Carbon Credits in Circulation: The issuance of carbon credit increases the number of credits in circulation within the market.

Carbon Credits in Circulation → (-) Carbon Credit Price: As the number of carbon credits in circulation increases, their price may decrease due to increased supply.

Carbon Credit Price → (-) Carbon Credit Retirement: A lower carbon credit price might disincentivize companies from retiring (or using) their carbon credits, as they become less valuable.

Carbon Credit Retirement → (-) Carbon Credits in Circulation: When carbon credits are retired, they are removed from circulation, reducing the overall supply.

Reinforcingcing Loop: CTaaS Adoption and CO_2 Emissions Reduction.

1) **CTaaS Awareness and Adoption Loop**

This is a reinforcing feedback loop. Increased awareness drives adoption.

CTaaS Awareness Growth Rate → (+) CTaaS Awareness: Increased awareness growth rate about CTaaS is likely to boost its awareness further accelerating the spread of information about the service

CTaaS Awareness → (+) CTaaS Adoption Rate: The faster the awareness grows the quicker the adoption rate increases

CTaaS Adoption Rate → (+) CTaaS Adoption: A higher adoption rate leads to further adoption of CTaaS.

CTaaS Adoption -> (+) CTaaS Awareness Growth Rate: As more entities adopt CTaaS (Carbon as a Service), awareness about this service grows.

Additional Influences

1) Policy Response has the ability to influence various aspects of the system, including carbon credit pricing and potentially even CTaaS adoption.
2) Technological Advancement results in efficient emissions reduction and potentially improve CTaaS solutions, which lead to the rate of CTaaS adoption.
3) Social-ecological Motivation influences the dynamics of a system, such as the public's attitude towards climate change and the market's demand for carbon reduction solutions.

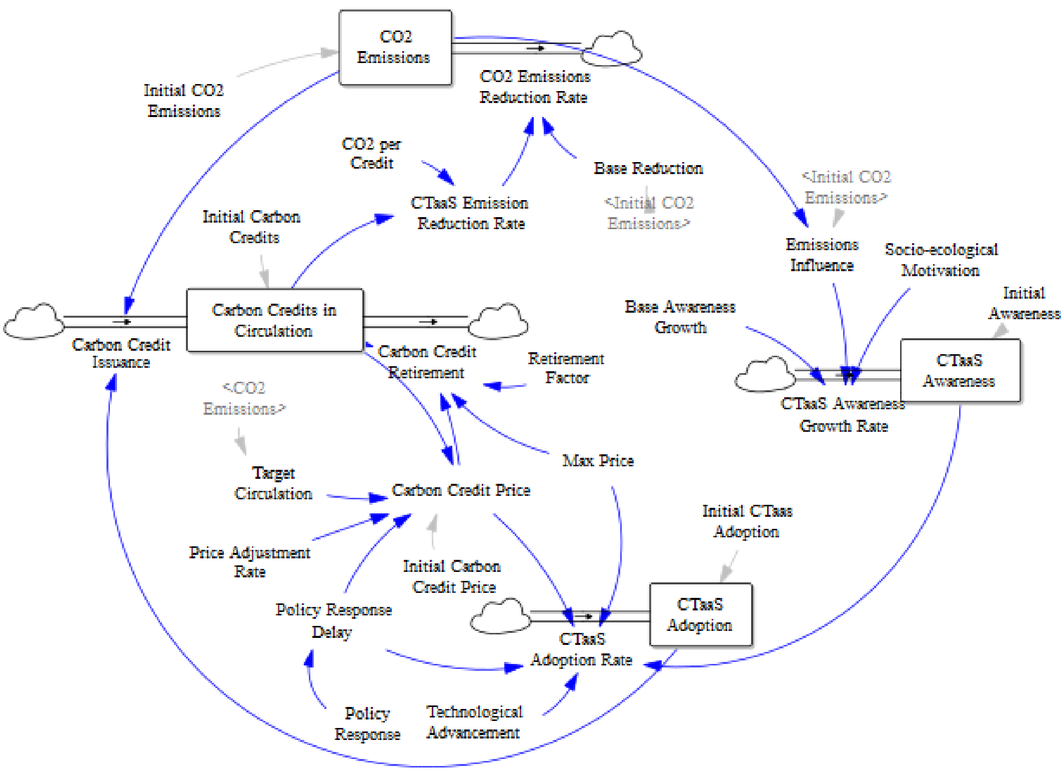

Figure 5.2 A Stock-flow diagram of Carbon Credit Trading-as-a-service
Source(s): Created by authors

Table 5.2 represents a stock-flow diagram of Carbon Credit Trading-as-a-service, illustrating the complex interactions between CO_2 emissions, carbon credits, and the adoption of CTaaS. The model highlights feedback loops, delays, and external influences that shape the dynamics of carbon reduction efforts. The model comprises key components as outlined below.

1. The stocks include the measurement of CO_2 emissions, the level of awareness regarding CTaaS, the adoption of CTaaS, and the quantity of carbon credits in circulation.

2. The flows consist of the rates of CO_2 emissions reduction, CTaaS awareness growth, CTaaS adoption, carbon credit issuance, and carbon credit retirement.

3. The auxiliary variables consist of CTaaS Emission Reduction Rate, Emissions Influence, Policy Response Delay, Carbon Credit Price, and Target Circulation.

4. The constants/parameters consist of Policy Response, Technological Advancement, Socio-ecological Motivation, Base Awareness Growth, Initial CO_2 Emissions, Initial Carbon Credits, Initial Carbon Credits Price, Initial CTaaS Adoption, Initial Awareness, Max Price, Price Adjustment Rate, Retirement Factor, Base Reduction, and CO_2 per Credit.

5.2.3 Model Parametrization

Carbon credits function principally as a supplementary tool rather than a primary solution for reducing emissions. This study utilizes CTaaS as a catalyst to enhance awareness of CO_2 emissions and encourage behavioral changes in energy consumption. The carbon market is complex and influenced by various factors, including the overall supply and demand for credits, the nature of projects generating credits and evolving international agreements (Yin & Kumagai, 2023). These factors will impact on the optimal number of credits that should enter the market. The model parameters are displayed in Table 5.2.

The stocks and equations can be clarified as follows.

1) CO_2 Emissions

Cumulative carbon dioxide (CO_2) emissions over a period of time, starting from an initial value and decreasing based on the CO_2 emissions reduction rate. The mathematical representation is:

$$CO2\ Emissions(t)=Initial\ CO2\ Emissions-\int_0^t CO2\ Emissions\ Reduction\ Rate(t)dt \qquad (1)$$

where, initial CO_2 Emissions = 7.60e+08 tCO_2.

According to Japan aims to reduce its greenhouse gas emissions by 46% in 2030 compared to 2013 levels (Ministry of Foreign Affairs of Japan, 2021). We assume that the initial CO_2 emission of 760 million tCO_2 represents that Japan's reduction efforts from 2024 to 2030 have been successful.

2) CTaaS Awareness

The level of awareness of CTaaS, which accumulates from a growth rate starting from an initial awareness level. The mathematical representation is:

$$CTaaS\ Awareness(t)=Initial\ Awareness+\int_0^t CTaaS\ Awareness\ Growth\ Rate(t)dt \qquad (2)$$

where, Initial Awareness = 0.1 (Percentage).

3) CTaaS Adoption

The level of CTaaS adoption over time, starting from an initial adoption level and increasing based on the adoption rate. The mathematical representation is:

$$CTaaS\ Adoption(t)=Initial\ CTaaS\ Adoption+\int_0^t CTaaS\ Adoption\ Rate(t)dt \qquad (3)$$

where, Initial CTaaS Adoption = 0.05 (Percentage).

4) Carbon Credits in Circulation

The total number of carbon credits in circulation, starting from an initial value and adjusted by the issuance and retirement rates. The mathematical representation is:

$$Carbon\ Credits\ in\ Circulation(t)=Initial\ Carbon\ Credits+\int_0^t [Carbon\ Credit\ Issuance(t)-Carbon\ Credit\ Retirement(t)]dt \qquad (4)$$

5) Carbon Credits Price

The total number of carbon credits in circulation, starting from an initial value and adjusted by the issuance and retirement rates. The mathematical representation is:

$$Carbon\ Credit\ Price = \frac{Price\ Adjustment\ Rate \times (Target\ Circulation - Carbon\ Credits\ in\ Circulation)}{(1 + Policy\ Response\ Delay)} \quad (5)$$

In Japan, carbon pricing consists of emissions trading systems (ETS) permit prices and carbon taxes, which will account for 73.3% of greenhouse gas (GHG) emissions in CO_2^e in 2021 (OECD, 2022). Therefore, we base the model on the assumption that by 2030, the carbon credit market will cover 100% of GHG emissions in CO_2^e. The carbon price varies from 289 JPY/tCO2 for the Japan carbon tax, to 14,000 JPY/tCO2 by 2022. Nomura Research Institute provided an estimate of the price range for carbon dioxide emissions, which is between 2,000 and 14,000 JPY per metric ton (Ishikawa, 2024). Therefore, we utilize this value as both the initial and highest carbon price in the model, measured in USD. The initial price is fixed at 13.65 USD per metric ton of CO_2, while the maximum price is 95.54 USD per metric ton of CO_2. The sources for other reference values can be found in Table 5.2.

Table 5.2 Model variables and initial value.

Variables	Value/Equation	Unit	Source
Stock			
CO_2 Emissions	CO2 Emissions(t)=Initial CO2 Emissions- $\int_0^t$ CO2 Emissions Reduction Rate(t)dt	tCO_2	Principle of mass balance in SD (Sterman, 2000)
CTaaS Awareness	CTaaS Awareness(t)=Initial Awareness+ $\int_0^t$ CTaaS Awareness Growth Rate(t)d(t)	Percentage	Definition calculated (Rogers, 2003)
CTaaS Adoption	CTaaS Adoption(t)=Initial CTaaS Adoption+ $\int_0^t$ CTaaS Awareness Growth Rate(t)d(t)	Percentage	Definition calculated (Bass, 2004)
Carbon Credits in Circulation	Carbon Credits in Circulation(t)= Initial Carbon Credits+ $\int_0^t$ [Issuance(t)-Carbon Credit Retirement(t)]dt	Credits	Weitzman (1974)
Flows			
CO_2 Emissions Reduction Rate	$\mathrm{CO2\ Emissions\ Reduction\ Rate(t)} = \mathrm{Base\ Reduction} + \mathrm{CTaaS\ Emission\ Reduction\ Rate(t)}$	tCO_2/Year	Yin & Kumagai (2023)
CTaaS Awareness Growth Rate	$\mathrm{CTaaS\ Awareness\ Growth\ Rate(t)} = \mathrm{Base\ Awareness\ Growth} + \mathrm{Socio} - \mathrm{ecological\ Motivation} \times 0.1 \times \mathrm{Emissions\ Influence(t)} \times (1 - \mathrm{CTaaS\ Awareness(t)}))$	Percentage /Year	Kothe et al. (2021)

Table 5.2 Model variables and initial value (Continued)

Variables	Value/Equation	Unit	Source
CTaaS Adoption Rate	$\text{CTaaS Adoption Rate(t)} = \text{CTaaS Awareness(t)} \times \text{Technological Advancement}^2 \times (1 - \text{Policy Response Delay}) \times \left(1 - \frac{\text{Carbon Credit Price(t)}}{\text{Max Price}}\right)$	Percentage /Year	Rogers (2003)
Carbon Credit Issuance	$\text{CO2 Emissions(t)} \times \text{CTaaS Adoption(t)}$	Credits /Year	OECD (2022)
Carbon Credit Retirement	$\text{Carbon Credit Retirement(t)} = \text{Carbon Credits in Circulation(t)} \times \text{Retirement Factor} \times (\frac{\text{Carbon Credit Price(t)}}{\text{Max Price}})$	Credits /Year	Japan Working Group (2022)
Auxiliary Variables			
CTaaS Emission Reduction Rate	$\text{CTaaS Emission Reduction Rate(t)} = \text{Carbon Credits in Circulation(t)} \times \text{CO2 per Credit} \times \text{Efficiency Factor}$	tCO_2/Year	PCC (2022)
Emissions Influence	$\text{EI} = \frac{\text{CO2 Emissions(t)}}{\text{Initial CO2 Emissions}})$	dmnl	PCC (2022)
Carbon Credit Price	$\text{Carbon Credit Price(t)} = (\text{Price Ajustment Rate} \times (\text{Target Circulation} - \text{Carbon Credit in Circulation(t)}/(1 + \text{Policy Response Delay(dt)}))$	\$/Credit	Ishikawa (2024)
Target Circulation	$\text{Target Circulation} = 0.2 \times \text{CO2 Emissions(t)}$	tCO_2	Target set as 20% of CO2 emissions
Policy Response	Scenario-based values: 0.2, 0.5, 0.8	dmnl	Based on scenario analysis
Technological Advancement	Scenario-based values: 0.2, 0.5, 0.8	dmnl	Based on scenario analysis
Socio-ecological Motivation	Scenario-based values: 0.2, 0.5, 0.8	dmnl	Based on scenario analysis
Base Awareness Growth	0.05	Percentage/ Year	Possible value (Rogers, 2003)
Base Reduction	0.04×Initial CO_2 Emissions	Percentage	(Yin & Kumagai, 2023)
CO_2 per Credit	1	tCO_2/Credit	(World Bank Group, 2022)
Initial CO_2 Emissions	7.6×10^8	tCO_2/Year	(Ministry of Foreign Affairs of Japan, 2021)
Initial Carbon Credits	0	Credits	Assumed zero for initial conditions
Initial Carbon Credits Price	13.65	\$/Credit	Ishikawa (2024)
Initial CTaaS Adoption	0.05 Similar adoption rates in early-stage technologies	Percentage	Possible value (Rogers, 2003)
Initial Awareness	0.1	Percentage	Possible value (Rogers, 2003)
Max Price	95.54	\$/Credit	Ishikawa (2024)
Price Adjustment Rate	0.01	\$/tCO_{2^2}	Assumed based on sensitivity analysis
Retirement Factor	0.37	dmnl	Calculated from Japan Working Group (2022)

5.2.4 Scenario-based Simulation and Results

The simulations depicted in **Figure 5.3** A simulation result with neutral, optimistic, and pessimistic scenariosFigure 5.3 examine the influence of technological advancement, policy responses, and socio-ecological motivation on CO_2 emissions. The simulation considers three scenarios: neutral, optimistic, and pessimistic, with varying degrees of interest factors, as indicated in **Table 5.3** Scenario approach for Carbon Credit Trading-as-a-serviceTable 5.3. The simulations assumed prompt CTaaS implementation in 2030 in order to observe the results until 2040.

The result demonstrates the projected CO_2 emissions over time under each scenario, highlighting the influence of various combinations of factors on efforts to reduce emissions. The optimistic scenario, characterized by the most favorable factors, shows the most significant reduction in CO_2 emissions, while the pessimistic scenario with the least favorable values displays a smaller reduction in emissions. The neutral scenario provides a baseline for comparison, as shown in

Figure 5.4 Result of scenario analysis.

Table 5.3 Scenario approach for Carbon Credit Trading-as-a-service

Factor	Simulation Value		
	Neutral	Optimistic	Pessimistic
Technology Advancement	0.5 (moderate progress)	0.8 (rapid progress)	0.2 (slow progress)
Policy Responses	0.5 (moderate stringency)	0.8 (strict policies)	0.2 (weak policies)
Social Movement Strength	0.5 (moderate pressure)	0.8 (strong pressure)	0.2 (weak pressure)

Source(s): Created by authors

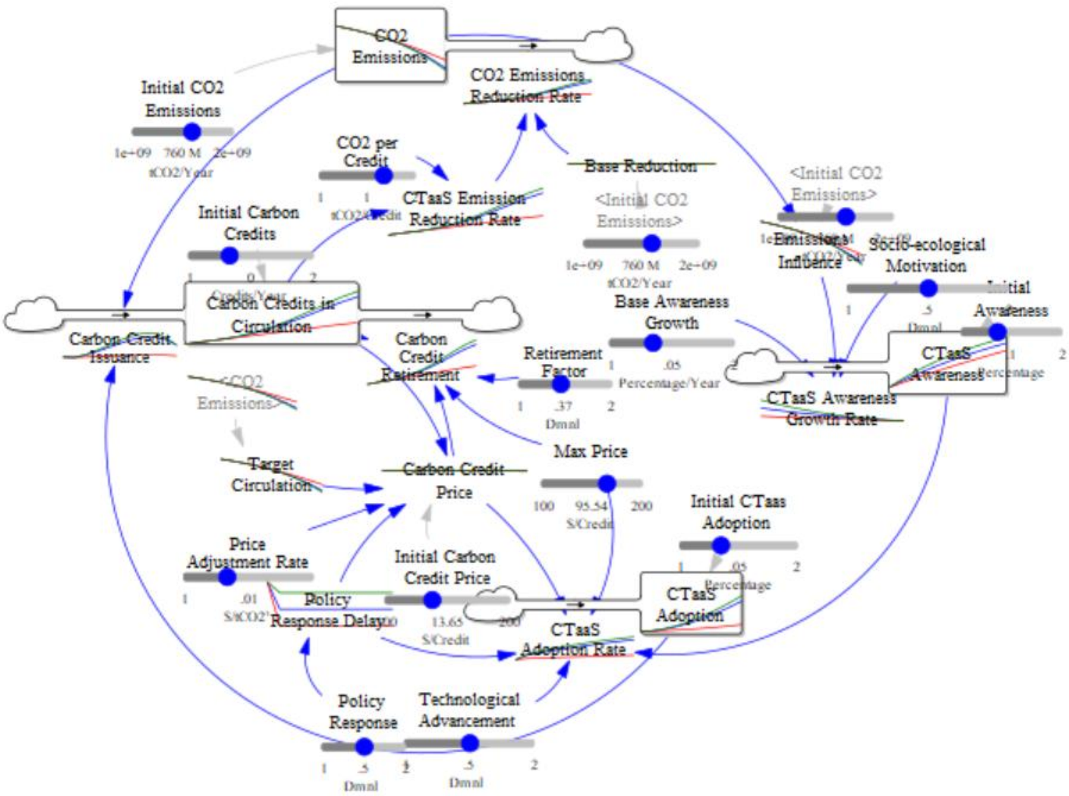

Figure 5.3 A simulation result with neutral, optimistic, and pessimistic scenarios
Source(s): Created by authors

The CO_2 emissions reduction rate, Carbon Credit Issuance and Circulation, and CTaaS Awareness consistently increase over time in all scenarios. The optimistic scenario assumes a significant increase in carbon credit issuance and circulation, indicating a more active carbon credit market. This is consistent with the rates of adoption and awareness.

The growth rate of CTaaS awareness initially grows high but gradually decreases over time. The optimistic scenario initially exhibits a slightly lower growth rate but eventually attains the lowest overall awareness of CTaaS. This suggests that awareness growth may slow down as emissions decrease.

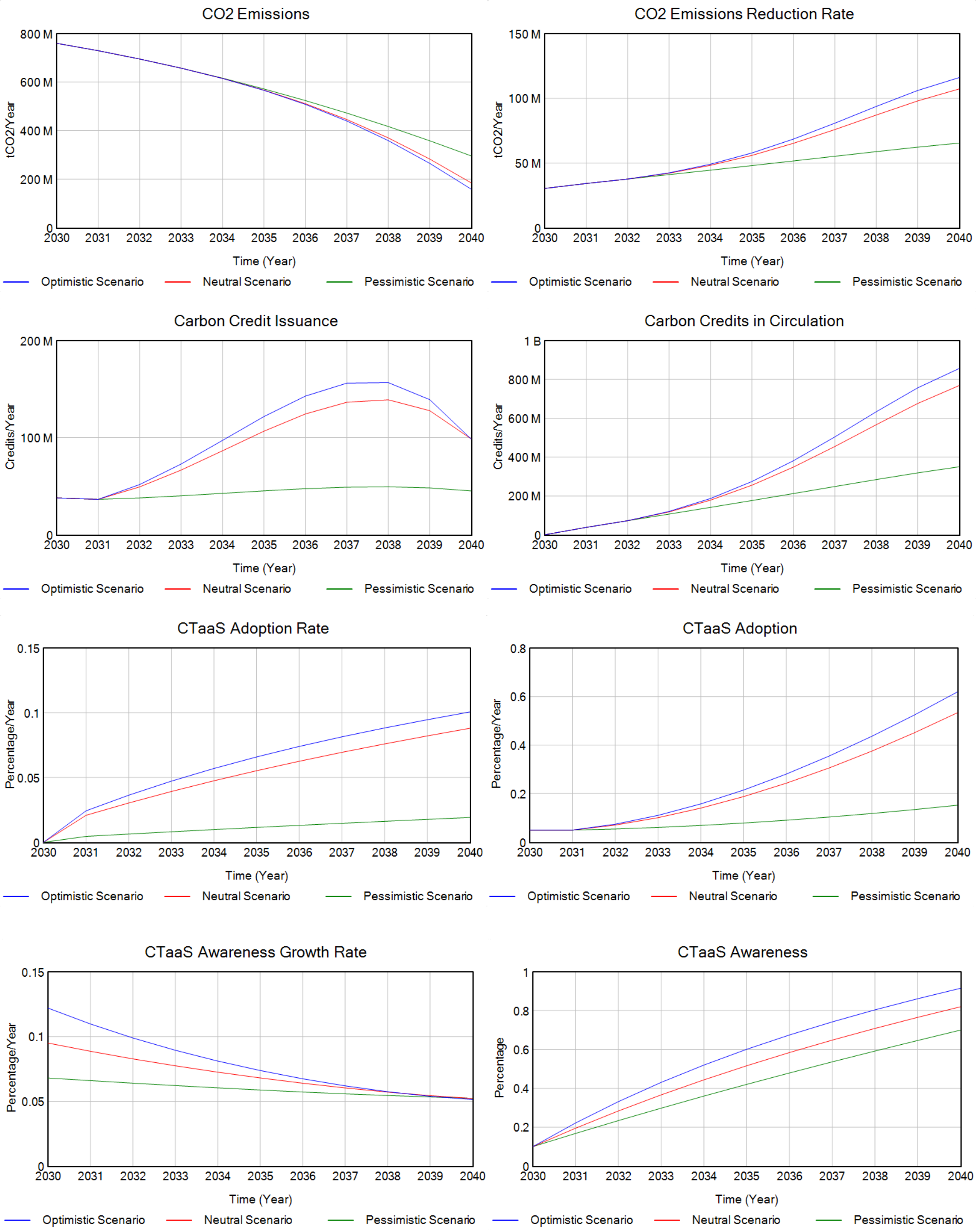

Figure 5.4 Result of scenario analysis

Source(s): Created by authors

5.2.5 System Dynamics Validation

Since this new service has not yet been implemented, validating the model is challenging. Therefore, the history test strategy is proposed for validating the system dynamics model's variable (Wen et al., 2016; Yang et al., 2021)

The sensitivity analysis demonstrates the parameters that have an influence on the system dynamics model's output. The measurement is determined by utilizing the Mean Absolute Deviation. Figure 5.5 illustrated the sensitivity analysis of CO_2 emissions using Vensim® PLE. The mean absolute deviation is obtained by comparing the base run with either a run that is 10% higher or 10% lower. The parameters with the highest sensitivity have the most significant influence on the dynamics of the system in the current model structure. The key sensitivity results of the system dynamics model's output can be summarized in Table 5.4.

1) CO_2 Emissions

The total amount of CO_2 emissions is greatly impacted by the initial CO_2 emissions. Additionally, Technological Advancement, CO_2 per credit, initial CTaaS adoption and policy response being key drivers, emphasizing the importance of technological progress and policy measures in mitigating emissions.

2) CO_2 Emissions Reduction Rate

The reduction rate of CO_2 emissions is primarily influenced by initial CO_2 emissions, technological advancement, the amount of CO_2 per credit and policy response. This reinforces the model's dependence on initial conditions and emphasizes the critical role of technology and the carbon credit system.

3) Carbon Credits in Circulation

The carbon credit model's output is influenced by technological advancement, initial CO_2 emissions, and policy response along with initial CTaaS adoption, max price, initial carbon credit price and socio-ecological motivation. These findings indicate that various factors significantly impact the carbon credit market.

4) CTaaS Adoption & Awareness

CTaaS adoption is primarily driven by technological advancement, policy response and max price, as well as socio-ecological motivation. While CTaaS awareness is influenced by base awareness growth, socio-ecological motivation and initial awareness. This indicates the intricate interaction of technological, economic, and social factors in CTaaS acceptance and perception.

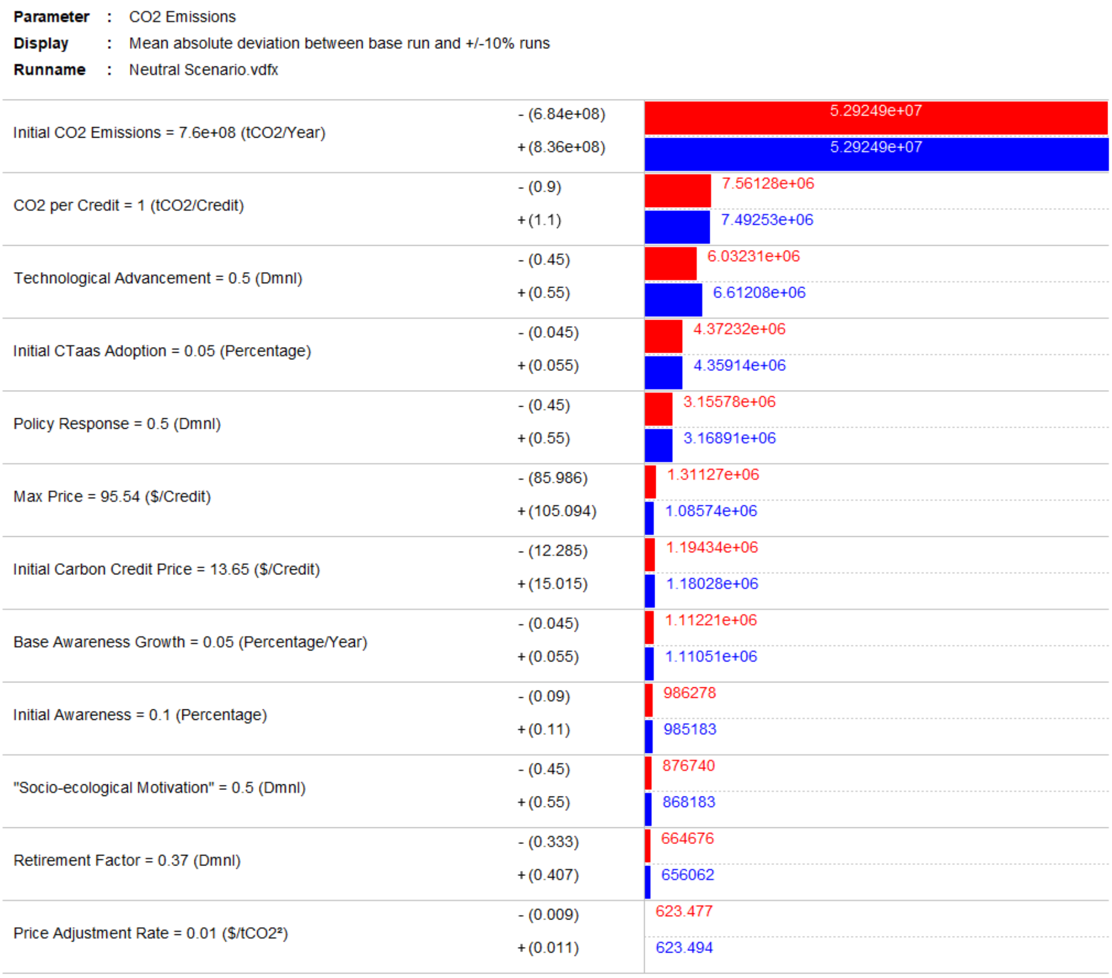

Figure 5.5 Sensitivity Analysis of CO_2 Emissions using Vensim® PLE

Source(s): Created by authors

Table 5.4 Summary of Model Sensitivity Analysis Results

Model Output	Key Influential Parameters	+10% Change	-10% Change
CO_2 Emissions	Initial CO_2 Emissions	5.29e+07	5.29e+07
	CO_2 per Credit	7.49e+06	7.56e+06
	Technological Advancement	6.61e+06	6.03e+06
	Initial CTaaS Adoption	4.36e+06	4.37e+06
	Policy Response	3.17e+06	3.16e+06
CO_2 Emissions Reduction Rate	Initial CO_2 Emissions	6.20e+06	6.20e+06
	Technological Advancement	3.48e+06	3.23e+06
	CO_2 per Credit	2.76e+06	2.83e+06
	Policy Response	1.69e+06	1.67e+06
Carbon Credits in Circulation	Technological Advancement	3.48e+07	3.23e+07
	Initial CO_2 Emissions	3.16e+07	3.16e+07
	Policy Response	1.69e+07	1.67e+07
	Initial CTaaS Adoption	1.12e+07	1.13e+07
CTaas Adoption	Technological Advancement	0.0374	0.0338
	Policy Response	0.0178	0.0178
	Base Awareness Growth	0.0074	0.0074
CTaas Awareness	Base Awareness Growth	0.0235	0.0225
	Socio-ecological Motivation	0.0125	0.0128
	Initial Awareness	0.0081	0.0081

Source(s): Created by authors

5.3 Conclusions

The study examines scenario-based simulation in accordance with the XaaS roadmap, which encompasses the policy, market, XaaS, and technology layers. The scenario development focuses on synthesizing possible scenarios, including neutral, optimistic, and pessimistic, in terms of technology, market, policy, and XaaS adoption.

The system dynamics model presented in this study examines the role of technological advancement, policy response, and socio-ecological motivation in driving CTaaS adoption and reducing CO_2 emissions. Moreover, it highlights the market mechanisms influencing carbon credit trading adoption and achievement. The simulation results show significant reductions in CO_2 emissions due to these factors.

Nevertheless, it is essential to recognize that these simulations are based on specific assumptions and models, which might not completely encompass the real-world complexities. However, utilizing the system dynamics approach provides a valuable holistic viewpoint, allowing for the examination of potential results under different scenarios. The actual outcomes may vary depending on numerous factors and unforeseen circumstances. This approach is one among several techniques that can be utilized to support strategic decision-making.

Further development can incorporate dynamic aspects to enhance realism. For instance, it can establish the relationship between research and development (R&D) and technology investment, economics, communication and education efforts, or marketing initiatives. The incorporation of dynamic elements can create a realistic and complex model that encompasses the evolving dynamics of the market. This can help policymakers and stakeholders in understanding the mechanisms that foster innovative businesses and facilitate the achievement of emission reduction targets.

Chapter 6
Dissertation Contribution

6.1 Answer for Research Questions

This research explores how XaaS Roadmapping, a framework merging Futures Literacy and XaaS business models, can address two crucial questions in our pursuit of a sustainable future.

Research Question 1: Knowledge Management for Sustainable Value Creation

[RQ1: How can knowledge management be transformed into creating sustainable value for society?]

Traditionally, knowledge management has focused on internal knowledge within organizations. This research proposes that XaaS roadmapping has the potential to transform knowledge management by integrating data mining, fostering collaboration, and establishing innovative ecosystems. The data-driven approach with topic modeling techniques on academic research and patents can leverage the latest knowledge and identify key elements of a roadmap. This ensures that service models address emerging public concerns. The research also emphasizes the importance of establishing innovative ecosystems that bring various stakeholders together to collaborate and develop solutions for societal challenges, such as decarbonization. The roadmapping process can incorporate knowledge management practices to align service innovations with market needs and sustainability goals. The research also emphasizes the importance of service innovations in promoting decarbonization and enhancing consumer well-being.

Research Question 2: Empowering People for Decarbonization and Well-Being

[RQ2: How can we empower people to use the future to develop service innovation roadmap for decarbonization and consumer well-being?]

XaaS Roadmapping goes beyond traditional approaches by encouraging active public participation in decarbonization. By cultivating Futures Literacy, participants enhance their capacity to think critically about future scenarios and develop adaptable XaaS roadmaps. This ensures that services are designed with a forward-thinking approach that emphasizes the importance of reducing carbon emissions and promoting well-being. The XaaS Roadmapping framework proposes a range of services designed to empower public participation in decarbonization initiatives. The case study, 'Carbon Credit Trading-as-a-Service', fosters a sense of urgency for households to actively reduce their carbon footprint. This research emphasizes the potential of XaaS models in enabling individuals to utilize the future to develop service innovation roadmaps for decarbonization and well-being. In addition, it promotes collective action and creates a knowledge ecosystem that drives sustainable value creation for future generations.

6.1.1 Academic Implications

The proposed XaaS roadmapping framework provides a structured and collaborative approach for businesses to participate in the shift toward a decarbonized society. Technology and service roadmapping primarily focus on structured planning for technology or service evolution within specific industries, often using foresight techniques, and market analysis (Kerr & Phaal, 2022). In contrast, XaaS roadmapping integrates Futures Literacy (FL) and scenario analysis, emphasizing service-oriented business transformation and decarbonization goals.

Traditional roadmapping (RM) has limitations that make it less adaptable to dynamic and evolving business landscapes. It tends to have a narrow focus, primarily emphasizing technology or service development while overlooking the broader ecosystem interactions essential for sustainable and scalable business models (Kishita et al., 2024; Phaal et al., 2024) Additionally, online collaboration, textual big data analysis, and scenario-based strategies are not integrated within a unified framework (Nishinaka et al., 2023). Unlike traditional approaches that follow a linear progression from development to commercialization, XaaS roadmapping employs a multi-stage, collaborative framework, leveraging knowledge co-creation and extensive textual data, including patents and academic papers, for ecosystem-wide innovation (Boonswasd et al., 2023). It also incorporates scenario-based strategies (optimistic, neutral, pessimistic) to ensure adaptability in an evolving business landscape (Hussain et al., 2017). While traditional roadmapping is widely applied in technology-driven sectors such as telecommunications and renewable energy, XaaS roadmapping fosters cross-industry collaboration, enabling new service-based business models like Carbon Credit Trading-as-a-Service (CTaaS). Ultimately, XaaS roadmapping provides a future-oriented, sustainable framework for businesses seeking to innovate beyond product ownership and drive societal transformation.

This study examines a knowledge co-creation workshop that enhances participants' futures literacy and expands service innovation within the ecosystem, reflecting a macro perspective intended to promote societal change. The XaaS roadmap is an adoption of a roadmapping method aiming to address the challenge of leveraging XaaS models within innovative ecosystems that drive decarbonization and enhance consumer well-being. In addition, the XaaS framework can be applied to the education sector by developing curricula and training programs focused on sustainability and future thinking.

The study's findings indicate that including Futures Literacy into the XaaS roadmapping framework enhances the strategic vision of businesses transitioning towards sustainable service models. The results reflect the initial hypothesis that FL fosters innovative value chains, especially in carbon credit trading services. Although FL is a valuable tool for strategic planning, its effectiveness depends on external factors such as regulatory frameworks and market readiness.

These findings align with prior research regarding the value of strategic foresight in corporate planning (Rohrbeck & Schwarz, 2013). The results support the hypothesis that Futures Literacy can serve as a catalyst for business model transformation, while also emphasizing the significance of complementary factors such as regulatory incentives and technological readiness. This highlights the necessity for further empirical validation across diverse industries to establish the broader applicability of this framework.

6.1.2 Practical Implications

The XaaS roadmapping framework provides managers with practical tools to transition from traditional business planning to innovative, consumer-oriented business models. The Carbon Credit Trading-as-a-Service (CTaaS) illustrates this by enabling the exchange of carbon credit among households, promoting active consumer engagement in attaining carbon neutrality (Huang et al., 2024). This business model supports the creation of smart cities, which significantly influences carbon reduction (Di Vaio et al., 2024). Additionally, the roadmap's collaborative approach engages industry experts at the macro level without a competitive mindset, enabling businesses to co-create innovative solutions and social infrastructure. Managers can leverage the roadmap to anticipate and address potential risks and opportunities, ensuring their firms remain adaptive and aligned with sustainability goals. In particular, the optimistic scenario, managers can proactively invest in research and development to accelerate the adoption of XaaS offerings and capitalize on emerging market opportunities. In the pessimistic scenario, managers can focus on risk mitigation strategies and develop contingency plans to address potential challenges such as policy inadequacies or public disengagement. In the neutral scenario, managers can adopt a balanced approach, maintain steady progress while remain adaptable to potential changes in the external environment. The scenario development process further aids managers by offering optimistic and pessimistic outlooks that emphasize the importance of strong policy support and public demand for sustainability. This paper also explores the economic benefits of the XaaS framework by examining its potential to drive household expense savings and create new market opportunities.

Managers should leverage Futures Literacy workshops as a tool for business model innovation. For instance, implementing scenario-based strategy sessions can improve decision-making under uncertainty.

6.1.3 Implications for Policymakers

Policymakers are essential for the effective execution of the XaaS strategy. Scenario development highlights the importance of robust policy frameworks to support sustainable practices and public engagement. The optimistic scenario underscores the need for proactive policy interventions to drive public demand for sustainability and to foster investment in decarbonization. Conversely, the pessimistic scenario warns of the consequences of underinvestment, inadequate policymaking, and public disengagement. Policymakers can use these insights to design robust regulatory measures, incentivize sustainable business models like CTaaS, and facilitate the development of smart cities. Furthermore, the collaborative approach demonstrated by the XaaS framework offers a model for cross-sector partnerships, which can enhance the efficacy of policy initiatives aimed at achieving carbon neutrality. For example, in the optimistic scenario, managers can proactively invest in research and development to accelerate the adoption of XaaS offerings and capitalize on emerging market opportunities. In the pessimistic scenario, managers can focus on risk mitigation strategies and develop contingency plans to address potential challenges such as policy inadequacies or public disengagement. In the neutral scenario, managers can adopt a balanced approach, maintain steady progress while remaining adaptable to potential changes in the external environment. The XaaS framework also has the potential to scale across regions and industries, considering factors such as technological readiness, regulatory frameworks, and cultural differences.

To enhance the efficacy of Futures Literacy in business strategy, policymakers ought to establish regulatory frameworks that promote foresight-oriented decision-making. Moreover, the formation of cross-sector foresight committees can improve collaboration among enterprises, government agencies, and research institutions, promoting a more proactive strategy for sustainable economic development.

6.1.4 Contribution to Knowledge Science

XaaS Roadmapping is a knowledge-based approach that integrates data mining and Futures Literacy to create an innovative service business for decarbonization. This research framework empowers individuals through actionable tools and fosters collaboration, accelerating the transition towards a sustainable future. This research framework demonstrates its practical application in service innovation development and XaaS concepts, offering a novel approach for envisioning and developing decarbonized service businesses. The knowledge co-creation workshops provide a valuable platform for collaboration and generating innovative ideas, which contributes to the advancement of knowledge science.

6.2 Conclusions

The XaaS roadmapping approach, which integrates futures literacy and expert brainstorming, has produced a well-structured and adaptable framework for fostering innovative and sustainable service businesses. The "Carbon Credit Trading-as-a-Service Roadmap" case study demonstrates the practical implementation of this approach.

This represents a significant step towards transforming business systems, led by the infrastructure industry sector. The XaaS roadmap establishes an entirely new business model on a large scale that encourages collaboration in the development of essential infrastructure, with a primary focus on achieving carbon neutrality. This roadmap is applicable for communication at both the micro and macro levels in business and policy contexts. Additionally, it provides organizations in the ecosystem with a chance to actively contribute to the growth of the XaaS sector. However, the roadmap for business transformation necessitates additional refinement for the sub-XaaS businesses.

This article contributes to the growing literature on XaaS, which focuses on service innovation. The framework provides a new approach by incorporating futures literacy into the XaaS roadmapping approach. This enhances organizations' capacity to anticipate and adapt to rapid technological breakthroughs and evolving market dynamics. The findings have practical implications for businesses, policymakers, and other interested parties seeking to leverage the potential of XaaS to drive decarbonization and establish a sustainable future. However, sustainable digital transformation is a complex process, requiring significant investment and ongoing evaluation to ensure seamless implementation (Nyagadza, 2022).

While previous studies on roadmapping primarily focus on technology and service strategy (Kerr & Phaal, 2022; Suh & Park, 2009), this research uniquely integrates Futures Literacy into the XaaS framework. Unlike conventional foresight approaches that focus on trend analysis, our study applies an anticipatory framework that enables businesses to co-create service value chains aligned with sustainability goals. This novel contribution positions our research within the broader discussion on foresight-driven business transformation.

To enhance the practical applicability of the proposed framework, businesses should incorporate structured Futures Literacy training sessions into their strategic planning processes. Moreover, adopting scenario-based decision-making can help firms proactively navigate market shifts and regulatory changes.

6.3 Limitations

This research primarily involves Japanese industry stakeholders, which may limit the generalizability of the findings to other geographical or industrial contexts. The number of fully engaged participants in the workshops and the iterative nature of the process may impact on the overall validity and reliability of the findings. Although data-driven methodologies are utilized in the roadmap approach, the development of future business innovations necessitates greater imagination and expertise from participants, which is beyond mere to examination of prior data.

One limitation of this study is the relatively small sample size of workshop participants, which may impact the generalizability of the findings. Future research should explore larger-scale implementations across different industry sectors to validate the scalability of this framework. Additionally, while our methodology integrates both qualitative insights and quantitative validation, further refinement is needed to establish standardized metrics for measuring the impact of Futures Literacy in business planning.

These findings illustrate the tangible benefits of Futures Literacy in fostering innovative service ecosystems. Companies adopting FL-based frameworks may gain a competitive advantage by proactively addressing sustainability challenges. However, successful implementation requires organizational commitment and policy support, reinforcing the need for a multi-stakeholder approach.

Future research should focus on refining the methodology to enhance anticipation accuracy and exploring the scalability of the XaaS framework across diverse industries and geographic contexts. This could involve conducting simulations to test the robustness of the framework under different conditions (Pora et al., 2022). Additionally, future research could explore the use of different data sources and analytical techniques to improve the accuracy of future predictions. These efforts will ensure the continued development of effective tools for both theoretical advancement and practical application in decarbonization initiatives.

6.4 Recommendations for Further Study

The XaaS roadmapping framework has potential for improvement by expanding its services, evaluating its impact on public participation and carbon footprint reduction, and adapting it to address sustainability challenges. The model's accuracy and predictive capabilities could be enhanced by incorporating additional factors and feedback loops. However, the study acknowledges potential implementation barriers, such as organizational resistance, limited resources, and technical difficulties. Future research should include cross-industry validation, enhancing the system dynamics model to reflect the evolving CTaaS ecosystem, and conducting longitudinal studies to track its long-term impact on service innovation, decarbonization efforts, and consumer well-being.

Further research could investigate the long-term impacts of XaaS models on the reduction of carbon emissions and the enhancement of consumer well-being, as well as the application of XaaS roadmap strategies across industries. Conducting research in these areas would be highly advantageous in providing valuable insights to organizations and policymakers.

Building on this, future studies could greatly benefit from exploring Structural Equation Modeling (SEM). Integrating SEM would allow for a more sophisticated analysis by enabling the testing of complex relationships between underlying factors. This approach would offer a more nuanced understanding of the elements influencing XaaS adoption and its contribution to decarbonization, ultimately refining the theoretical framework and providing more robust empirical insights into the multifaceted challenges and opportunities within the evolving XaaS ecosystem.

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PUBLICATIONS

Papers published in journals

1. Porruthai Boonswasd, H. M. Belal and Kunio Shirahada, Building Decarbonized Society: An XaaS Roadmapping Approach, Management of Environmental Quality: An International Journal, pp. 1-21, 2025.

The relation between this publication and the claim of dissertation is to introduce a novel XaaS roadmapping framework that integrates Futures Literacy (FL) with the Everything-as-a-Service (XaaS) business model to promote decarbonization and enhance consumer well-being. The methodology includes knowledge co-creation workshops and the use of data-driven techniques that consist of topic modeling and patent analysis, which constitute the primary case study of the "Carbon Credit Trading-as-a-Service (CTaaS) Roadmap". The article aims to present the framework and its practical application, reflecting the broader research outlined in the dissertation.

International Conference Proceeding

1. Porruthai Boonswasd, Rujira Chaysiri and Kunio Shirahada, Situational Assessment of XaaS Roadmap for Decarbonization Society using System Dynamics, In: Proceedings of 2023 Portland International Conference on Management of Engineering and Technology (PICMET), 147-157, 23-27 July 2023, Monterrey, Mexico.

The relation between this publication and the claim of dissertation is to conduct a XaaS Roadmap workshop to develop innovative service ideas and roadmap, as well as situational assessments, which will lead to transformative knowledge management toward a decarbonization society and consumer well-being in the major research.

2. Porruthai Boonswasd and Kunio Shirahada, Exploring Trends in Self-Service Innovation to Boost Social Engagement among the Elderly from 2000 to 2022, In: Proceeding of the 18th International Research Symposium on Service Excellence in Management (QUIS18), 563-576, 10-23 June 2023, Hanoi, Vietnam.

The relation between this publication and the claim of dissertation is patent analysis to anticipate future technological trends as part of the major research methodology.

3. Porruthai Boonswasd and Kunio Shirahada, Empowering Futures Literacy through a Knowledge-based Service Innovation Workshop, AHFE (2022) International Conference, In: Proceedings of the Human Side of Service Engineering, 109–116, 24-28 July 2022, New York, USA.

The relation between this pumajor and the claim of dissertation is to organize a knowledge-based service innovation workshop to develop innovative service ideas by encouraging future literacy, which is a pre-workshop that leads to a sustainable XaaS roadmap in the major research.

4. Porruthai Boonswasd, Pakawat Limsiriwattanakul, and Kunio Shirahada, Revealing Trends in Telemedicine Technology using Patent Analysis, In: Proceedings of International Engineering and Technology Management Summit 2021– ETMS2021, 147-157, 16-17 September 2021, Istanbul, Turkey.

The relation between this publication and the dissertation claim is patent analysis to anticipate future technological trends as part of the major research methodology.