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Strategic Technology Roadmapping (STRM): A process enhancing corporate foresight and strategic planning in Repsol Technology Lab

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DOCTORAL THESIS

Title	Strategic Technology Roadmapping (STRM): A process enhancing corporate foresight and strategic planning in Repsol Technology Lab
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As I write these words, it marks the approaching end of my doctoral journey. Looking back at my past self four years ago, my mindset at that time, and comparing it to who I am now, I suddenly realize the true meaning of pursuing a doctorate. The four-year journey of the Ph.D. has offered me more than a profound understanding of a specific field. More importantly, it has endowed me with the capacity to explore the nature of things, the unwavering spirit to strive for perfection. This signifies a higher state of mind and a more open worldview of me. I truly believe that, without all of you, I would not have encountered this better version of myself.

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ABSTRACT

Technology roadmapping (TRM) or roadmapping is nowadays one of the most widely used techniques for supporting organizations with their strategic planning, innovation and foresight activities. The current literature in TRM has identified the importance of sustaining and maintaining the use of that in an organization for improving its strategic responsiveness and innovation capacity. However, the current research has made limited efforts in investigating how roadmapping can be effectively implemented and integrated into organizational routine to support ongoing organizational decision-makings. The lack of adequate documentation of the follow-up effort has led to a scarcity of longitudinal evidence indicating the potential level of performance that may be achieved, hence reducing the organization's confidence in employing this technique. In search for the answer, I carried out an action research study at Repsol Technology Lab. Over the course of 30 months spanning from July 2021 to December 2023, a roadmapping-based foresight process, known as Strategic Technology Roadmapping (STRM) process, was developed and executed for two complete research cycles and achieved positive outcomes in regards to strategy, organization and innovation performance. Currently, the STRM process has been effectively maintained and incorporated into its organizational process to be executed regularly. This action research contributes to the roadmapping literature by: 1) offering practical guidance on how to effectively customize, develop and sustain the utilization of roadmapping process in an organization; 2) providing empirical evidence on the various value contributions of using roadmapping-based foresight tool in an organization; and 3) sharing valuable lessons learned and key success factors indicated throughout the process from initiation to integration of roadmapping into organizational processes.

RESUMEN

El roadmapping tecnológico (TRM) o roadmapping es hoy en día una de las técnicas más utilizadas para apoyar a las organizaciones en sus actividades de planificación estratégica, innovación y prospectiva. La literatura actual sobre TRM ha identificado la importancia de sostener y mantener el uso de eso en una organización para mejorar su capacidad de respuesta estratégica y capacidad de innovación. Sin embargo, se ha constatado un déficit de investigación en la literatura académica para arrojar luz sobre cómo la hoja de ruta (roadmapping) se puede implementar e integrar de manera efectiva en la rutina organizacional para respaldar la toma de decisiones organizacionales en curso. La falta de documentación adecuada del esfuerzo de seguimiento ha llevado a una escasez de evidencia longitudinal que indique el nivel potencial de desempeño que se puede lograr, reduciendo así la confianza de la organización en el empleo de esta técnica. En busca de la respuesta, realicé un estudio de investigación en acción en el Repsol Technology Lab. En el transcurso de 30 meses, desde julio de 2021 hasta diciembre de 2023, se desarrolló y ejecutó un proceso de prospectiva basado en hojas de ruta, conocido como proceso de Roadmapping Tecnológico Estratégico (STRM), durante dos ciclos completos de investigación, logrando resultados positivos en términos de desempeño en estrategia, organización, e innovación. Actualmente, el proceso STRM se ha mantenido e incorporado efectivamente a su proceso organizacional para ser ejecutado periódicamente. Esta investigación de acción contribuye a la literatura sobre roadmapping en: 1) ofrecer orientación práctica sobre cómo personalizar, desarrollar y sostener de manera efectiva la utilización del proceso de roadmapping en una organización; 2) proporcionar evidencia empírica sobre las diversas contribuciones de valor del uso de herramientas de previsión basadas en roadmapping en una organización; y 3) compartir valiosas lecciones aprendidas y factores clave de éxito indicados a lo largo del proceso, desde el inicio hasta la integración del roadmapping en los procesos organizacionales.

RESUM

El roadmapping tecnològic (TRM) o roadmapping és avui una de les tècniques més utilitzades per donar suport a les organitzacions en les seves activitats de planificació estratègica, innovació i prospectiva. La literatura actual sobre TRM ha identificat la importància de sostenir i mantenir-ne l'ús en una organització per millorar la seva capacitat de resposta estratègica i capacitat d'innovació. No obstant això, s'han trobat poques evidències en la literatura actual per investigar com el full de ruta es pot implementar i integrar de manera efectiva a la rutina organitzacional per recolzar la presa de decisions en curs. La manca de documentació adequada de l'esforç de seguiment ha portat a una escassetat d'evidència longitudinal que indiqui el nivell potencial d'acompliment que es pot aconseguir, reduint així la confiança de l'organització en l'ocupació d'aquesta tècnica. A la recerca de la resposta, vaig realitzar un estudi de recerca en acció al Repsol Technology Lab. En el transcurs de 30 mesos, des de juliol de 2021 fins a desembre de 2023, es va desenvolupar i executar un procés de prospectiva basat en fulls de ruta, conegut com procés de Roadmapping Tecnològic Estratègic (STRM), durant dos cicles complets de recerca, el qual va aconseguir resultats positius en termes d'exercici en estratègia, organització, i innovació. Actualment, el procés STRM s'ha mantingut efectivament i s'ha incorporat al seu procés organitzacional per ser executat periòdicament. Aquesta investigació en acció contribueix a la literatura sobre roadmapping en: 1) oferir orientació pràctica sobre com personalitzar, desenvolupar i sostenir de manera efectiva la utilització del procés de roadmapping en una organització; 2) proporcionar evidència empírica sobre les diverses contribucions de valor de l'ús d'eines de previsió basades en roadmapping a una organització; i 3) compartir lliçons apreses valuoses i factors clau d'èxit indicats al llarg del procés, des de l'inici fins a la integració del roadmapping en els processos organitzacionals.

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Chapter 1
Introduction

We are in our journey in the fight against climate change. Repsol is the first company announced the commitment of reaching net zero emissions by 2050 (Repsol, 2024). We are continuously working toward this goal by developing and investing emerging technologies. The COVID pandemic has also placed science, technology, and innovation at the center of the international economy. In this scenario, instruments and strategic tools that allow a company to detect, develop, and promote of emerging technologies with disruptive potential are of special importance.

Kerr et al. (2013) present seven principles that provide a conceptual underpinning for the development of practically relevant and academic sound strategic technology management tools and toolkits, that is, human-centric, workshop-based, neutrally facilitated, lightly processed, modular, scalable, and visual. Technology roadmapping (TRM) or roadmapping is a tool that represents and explores the simultaneous relationships between markets, products, and technologies in a structured, temporal, and graphical way (Phaal et al., 2004a). It fuses these dimensions at different levels of the firm into a framework that sustains dialogue and informs decision-making. It is scalable in application scope for different levels of analysis, supporting strategy not only at firm level but also at sector and regional/national levels (e.g., Sydow and Müller-Seitz, 2020; Daim et al., 2016; Gallegos Rivero and Daim, 2017). TRM has met all the key principles as a strategic technology management tool, thus, is recognized as one of the most comprehensive tools to foster strategic management and planning (More et al., 2015; Jou and Yuan, 2016).

The industrial roots of TRM can be tracked back to the 1960s (Kerr and Phaal, 2020). Ever since the publication of 'Motolora's technology roadmap process' (Willyard and mcclees, 1987), TRM as a method that plans for technology R&D has made a considerable impact and raised much awareness mainly from industrial engineering groups (Kerr and Phaal, 2022). The technique was then extended to other innovative large firms including Phillips (Groenveld, 1997), Royal Mail (Wells et al., 2004), Lucent Technologies (Albright and Kappel, 2003), General Motors (Lee et al., 2009), and Lego (Kerr, et al., 2019). A survey completed in the UK for 2000 manufacturing firms indicates that 10% of medium-to-large companies had applied TRM at the end of the 1990s (Phaal and Farrukh, 2000). At the beginning of the 21st century, the scope of roadmaps expanded to cover policy makings at the national level (Vishnevskiy et al., 2015; Amer and Daim, 2010). Governments first used roadmapping to promote the development of existing industries, and then to introduce emerging technological solutions to social and economic development (McDowall, 2012; UNFCC, 2013). Over more than five decades of application, roadmapping has evolved to cover a more general and flexible business and industrial approach which can be adapted to virtually any strategic context and for many different purposes - for example, new product development, service design, business model change, supply chain management, and digital transformation, in many sectors and at all levels from components to products and portfolios, from firms to sectors, nationally and internationally (Kerr and Phaal, 2022).

Although roadmapping had been practiced for some time, academic researchers didn't show their interest in this technique until early 2000 (Phaal et al., 2005; Gerdsri et al., 2008). Authors from the UK, South Korea, and the USA were predominant in the publications (De Alcantara and Martens, 2018). A high concentration of studies comes from Seoul National University in South Korea, as well as the Center for Technology Management at the Department of Engineering at the University of Cambridge in the UK, led by Dr. Robert Phaal, who has been the most active researcher in the research field of roadmapping. TRM as a conceptual tool has been constantly improved and modified to reflect the nature of the industry (Vishnevskiy et al., 2015). The studies in roadmapping have increased over time, but it is still in an exploratory phase of research (Carvalho et al., 2013).

The focus of my PhD research is on the application of roadmapping in corporate foresight in a real firm setting. Under the 'doctorados industriales' program by Generalitat de Catalunya, I have worked and researched in Repsol Technology Lab (hereinafter "Tech Lab") from the second to the fourth year of my PhD studies (July 2021 – July 2024). Repsol is a leading energy company in Europe, with its headquarters located in Madrid, Spain. Tech Lab functions as the research and development (R&D) center for Repsol. During the first year of my PhD study (September 2020 - July 2021), I selected TRM as my area of interest and worked with Dr. Xavier Ferrás to write a paper on a systematic literature review of the case studies applied in the TRM field.[1] In July 2021, I officially joined Tech Lab and started my job as a Deep Tech scientist. Following several months of training and communicating with colleagues from different departments to gain insights into the challenges of the current innovation process, we decided to introduce a roadmapping-based foresight process. This process integrates innovation foresight and strategic planning at the Tech Lab level (i.e., the business level) to be implemented as a preliminary step prior to the existing innovation process known as "Demand Management". This has become my research project inside the Tech Lab. Over the course of 30 months spanning from July 2021 to December 2023, an action research approach was applied to develop and implement a roadmapping-based foresight process inside the Tech Lab. This action research entails two action and reflection cycles that shows how Tech Lab initiated roadmapping by trialing a reference process, and then, based on feedback and lessons learned, adapted it to create its own roadmapping process and integrated it into the ongoing organizational process. At the

[1] The paper "Case study as a methodological foundation for Technology Roadmapping (TRM): Literature review and future research agenda" was published in the Journal of Engineering and Technology Management in February, 2023.

moment, this implementation has been effectively incorporated into the existing organizational processes and has been maintained within Tech Lab.

My doctoral research makes several key contributions to the field of roadmapping and innovation management in general, from both academic and practical perspectives. From the academic perspective, the systematic literature review contributes to the roadmapping literature by providing a thorough presentation of the current literature of the applied case studies. It suggests a way to improve the credibility and generalizability of the case study method utilized in the roadmapping research, and points out the insufficient stage (i.e., the follow-up stage), allowing academics to put on more focus to enrich the theory. Then, the longitudinal action research conducted in Tech Lab intends to fill the gap by expanding the scope of investigation to include the follow-up stage and to show the importance of maintaining a follow-up stage when applying roadmapping in an organization. From the practical perspective, the literature review represents a helpful tool for practitioners to seek the most recent findings and applications within the current body of knowledge. The action research, then, illustrates a particular application in roadmapping, an organizational roadmapping-based foresight methodology, and provides invaluable guidance on how an organization can efficiently design, develop, and integrate that methodology into the organization. By indicating various kinds of value contributions of the implementation, it also enhances confidence and improves the likelihood of success for other companies looking to adopt a similar roadmapping approach. More generally, the action research provides valuable insights and a practical methodology that can assist other organizations in enhancing their strategic planning and foresight activities.

The rest of the doctoral thesis is structured as follows: Following this introduction, Chapter 2 begins with a thorough literature review on TRM, which covers its basic concepts and definitions. This is followed by a systematic literature review of the case studies applied in this field, providing the state-of-the-art of knowledge on this topic. From Chapter 3, the research project in Tech Lab is illustrated. It begins with a brief introduction of Tech Lab, followed by an explanation of the challenges, and the motivations and reasons behind the adoption of roadmapping. Chapter 4 outlines the research objectives and methodologies. Then, the two action research cycles that Tech Lab undertook to implement and enhance the roadmapping process over a thirty-month period are thoroughly detailed in Chapter 5. A customized process in Tech Lab, Strategic Technology Roadmapping (STRM) process, is presented in this Chapter, and it concludes with an analysis of outcomes that were obtained. Chapter 6 discusses the key elements that lead to success and the distinctive contribution of the whole process in addressing grand challenges, along with the limitations of this research and the suggested areas for future research. The thesis is concluded in Chapter 7, with the contributions reviewed at the end.

Chapter 2
Literature review

2.1 Technology Roadmapping (TRM)

2.1.1 Basic concepts of TRM

TRM is a flexible technique for supporting strategic management of technology and has been widely accepted in both industry and academia (Lee and Park, 2005; Phaal et al., 2004a; Rinne, 2004). It provides a graphical means for exploring and communicating the relationships among markets, products, and technologies over time, linking the business strategy to the evolution of the product features (Albright and Kappel, 2003; Lee and Park, 2005). Figure 2.1 represents a general full-scale technology roadmap architecture (Phaal and Muller, 2009), in which the elements used to build a technology roadmap are not limited to but are strongly dependent on the following: 1) time-frame, designed to 'know-when' to fit into a particular situation; 2) top vertical layers, related to market approach, or 'know-why', designating factors leading to value creation; 3) bottom layers indicate companies 'know-how', corresponding to consolidated or in-development technology and applied knowledge; 4) intermediate layers present 'know-what', comprising the carriage agent to deliver knowledge and technologies to meet market needs; and 5) linkages and the discontinuities between components of different layers (Phaal et al., 2004a). With these elements shown on the roadmap, it tries to answer the questions of: 1) where do we want to go? 2) where are we now? and 3) how can we get there? (Phaal and Muller, 2009).

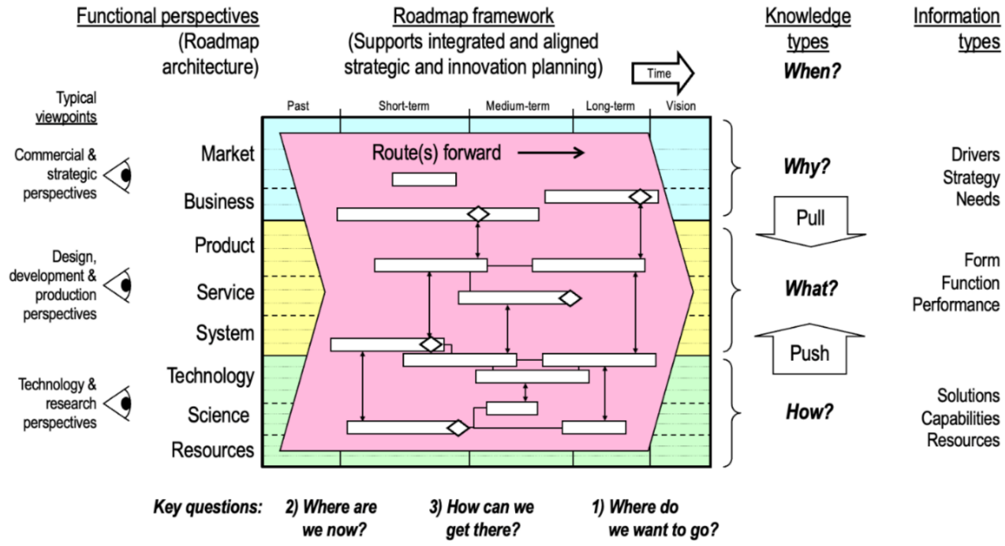

Figure 2.1: A general full-scale technology roadmap architecture (retrieved from Phaal and Muller, 2009)

There are two basic strategies in technology planning. The market-pull strategy is a strategy containing activities oriented toward the marketing concept emphasizing the requirements of a targeted market (Von Hippel, 2001). In contrast, the technology-push strategy focuses on the invention without concern for marketing attractiveness and application of technologies to products. It follows technological capabilities that exist within firms where the application is developed and subsequently 'pushed' into the market (Isoherranen and Kess, 2011). In terms of classification, there have been a number of attempts to classify the types of roadmaps. Lee and Park (2005) suggest eight types of technology roadmaps as follows: product family map, product driver map, product planning roadmap, product evolution roadmap, technology portfolio map, technology position map, technology prospect roadmap, and technology trend roadmap. Phaal et al. (2004) suggest sixteen types of roadmap depending on their intended purposes and graphical formats. Different classifications of TRM demonstrate TRM's flexibility and extensive applicability.

2.1.2 Definitions of “roadmap” and “roadmapping”

Although technology roadmap and roadmapping have been defined numerous times (Garcia and Bray, 1997; Galvin, 1998; Phaal et al., 2004a; UNFCCC, 2013), there has been a lack of rigorous and robust definitions until Kerr and Phaal (2022) provide one in their recent work. They define roadmap as “a structured visual chronology of strategic intent”, and roadmapping as “the application of a temporal-spatial structured strategic lens”. The term "structure" relates to the governing framework that illustrates the interrelationships between evolving and developing markets, products, and technologies across time, thereby presenting both the commercial and technological perspectives in a roadmap.

2.2 A systematic literature review in TRM case studies

In May 2021, Dr. Xavier Ferrás and I conducted a systematic literature review in the case studies applied in TRM research with the paper later published in Feburary 2023 (Ding and Ferrás Hernández, 2023). This section provides a detailed explanation of the study. Instead of a full paper, the motivation, methodology, summary of findings and discussions of the study are presented. Given the case study as a prominent methodology utilized in the TRM research, the findings from this study are used to accurately reflect the current state of knowledge in this field. It enables me to identify the research gap and investigate it in a real firm setting through my following case research.

2.2.1 Motivation of the study

Previous literature reviews in TRM emphasized investigating the concept of TRM, which includes the TRM process, models, tools, and effects, to provide the state art of roadmapping research and practices. For example, Vatananan and Gerdsri (2012) reviewed 172 publications in the field of TRM in major journals and conferences from 1987 to 2009. From the literature, the paper summarized the concepts and objectives of TRM, benefits of TRM to individuals and organizations, functions and uses of TRM, architectures, approaches for development, and supporting tools. The paper identified the issue of keeping the roadmap ‘alive’ as the key challenge in the field. Gerdsri et al. (2013) reviewed 229 TRM concept articles retrieved from the Scopus database from 1987 to 2010, where the concept only covers the structure, function, and process of roadmapping, rather than the variety of TRM applications. De Alcantara and Martens (2018) systematically investigated 124 articles from 2002 to 2017. The research mixed a bibliometric study with network analysis and focused on the content that connects TRM and strategy to present a set of roadmapping models associated with the theme. With the analysis of citation and co-citation of articles, the paper creates an exhaustive clustering and listing of the most relevant and impactful TRM models, allowing scholars to examine reputable works in this field.

Instead of researching into the TRM concept again to provide an update, we chose to investigate the TRM case studies for several reasons. First, we find that the simple concept of TRM lacks a complete methodology and commonly accepted standard that allow the practitioners to follow (Nakamura et al., 2006), most of the researchers and practitioners explore a practical structure of TRM by applying exploratory qualitative approaches based on case studies (Cheng et al., 2014). This highlights the importance of researching the field of TRM through the lens of the applications. Second, from the methodological point of view, although there has been no reflective focus on a single and major methodology that researchers have used to study TRM, such methodological reflects are common in other management fields (e.g., Easton, 2010; Moreno-Camacho et al., 2019; Saade and Nijher, 2016). Given the growth of the TRM research over the last two decades, we find the need to understand the underpinning methodologies that have been used to advance the TRM field, particularly with respect to case study methods. After many years of adequate usage of case study methods and the renewed interest in TRM due to enhanced technological competition, it is crucial to review the progress of research within the field that is underpinned by this robust methodological approach. An overview of recent themes and trends also enables researchers to work on relevant fields offering further insights into previously neglected areas of research.

Therefore, we undertake a systematic literature review of the case studies applied in the TRM research. Given the growing importance of TRM in accelerating and minimizing risks in technology transfer and corporate technological strategy, the aim of the literature review is threefold: 1) to discover and update the themes and applications of TRM, shedding light and strength on the set of tools used to develop TRM; 2) to improve the case study in this field through the assessment on the methodology; and 3) to identify trends and anticipate emerging research directions. We aim to contribute to TRM research by providing a complete presentation of the current applied case studies, identifying trends and research gaps for future academics and practitioners to collaborate for better use of TRM.

2.2.2 Methodology

Seventy-nine case studies were reviewed from 2003 to 2020, following a comprehensive systematic literature review approach developed by Tranfield et al. (2003). It involves two processes - the first process concerns defining review protocols and field mapping, and the second process reports the findings. We focused on the concept of technology roadmap introduced by Kerr and Phaal (2022), which emphasizes both commercial and technological perspectives in a roadmap. A technology roadmap that only encompasses the development of the technological dimension was not our focus.

First, the protocol contains information on the precise questions that the study addresses, the study’s population, the search strategy as well as the criteria for the inclusion and exclusion of studies (Tranfield et al., 2003). This literature review began with identifying the search terms and databases. Based on the objective of this research, two research domains are involved: 1) technology roadmapping; and 2) case study. We selected the most relevant search terms for each domain, and we used the search string as “technology roadmap*” AND (“case study” OR “case method” OR “case example”) in a title-abstract-keywords searching approach. Four academic databases were chosen in the search: Scopus, Web of Science, ScienceDirect, and EBSCO. Table 2.1 summarizes the searching information.

Table 2.1: Search terms and databases

Research domain	**Search terms**	**Search string in title-abstract-keywords domain**	**Databases**
technology roadmapping	“technology roadmap*”	“technology roadmap*” AND (“case study” OR “case method” OR “case example”)	Scopus Web of Science ScienceDirect EBSCO
case study	“case study”		
	“case method”		
	“case example”		

The initial results identified through 4 databases yielded 305 papers. After 129 duplications among databases were removed, we conducted a review of all 176 articles searched from the databases. In the screening phase, we included articles from journals, conferences, and book chapters. We excluded the papers that were not in English, not peer-reviewed academic literature, not related to the research of conducting case study methods in the topic of TRM. It gave results of 110 full-text papers for the assessment for eligibility. Thirty-one papers were identified not to match with the definition of technology roadmap, therefore, were further removed. Such studies only include the dimension of technology development in the roadmap, where the link with the commercial dimension is missing. Ended searching by May 2021, a total of 79 articles that met the defined protocol were included in the review. We used a PRISMA flowchart in Figure 2.2 to depict the process of filtering the sample of the study (Moher et al., 2009). The PRISMA (“Preferred Reporting Items for Systematic reviews and Meta-Analyses”) method, as a graphical representation of the flow of information through different phases of systematic literature reviews, was originally applied in the medical area, and now has been largely utilized in management studies as well (e.g., Buer et al., 2018; Ding et al., 2023; Macke and Genari, 2019).

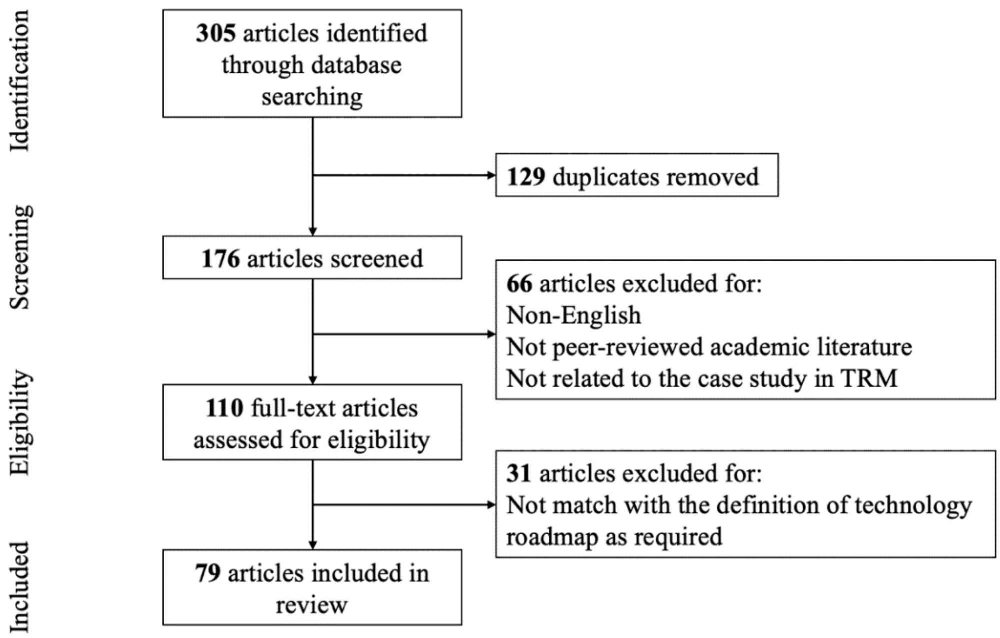

Figure 2.2: The PRISMA flowchart of the systematic literature review (adapted from Moher et al., 2009)

2.2.3 General description of the literature

The basic information of all 79 articles were mapped out in a spreadsheet. The mapping fields include the article's name, authors, year of publication, journal, theme, number of cases, location, sector, level of study, and notes on the key findings. The extraction form can reduce human error and provide a historical record of the decisions made during the process (Tranfield et al., 2003). A detailed illustration of the essential dimensions and summaries of the identified 79 studies can be found in Appendix A. We analyzed the general classifications of those articles, including the research method, the location of cases, and sector analysis. The year of publications is not listed here due to the release of several Special Issues (e.g., *Technological Forecasting and Social Change* in 2004, *Journal of Engineering and Technology*

Management in 2019, *IEEE Transactions on Engineering Management* in 2021) that reduced the number of publications the year before and after, making interpretation difficult.

First, we conduct a research method-based analysis of the papers, as shown in Figure 2.3. Sixty-eight of the 79 studies (86.1%) use a single case study methodology, while 11 articles (13.9%) conduct several cases as part of a single study. In terms of the case study method, a mixed or hybrid approach, which combines qualitative and quantitative methods, was used in nearly half of the research (42.9%), followed by qualitative methods (25%), quantitative methods and conceptual approaches (both 13.1%). The conceptual studies are those articles in which there is no mention of data gathering methods and the cases are merely simple illustrative examples.

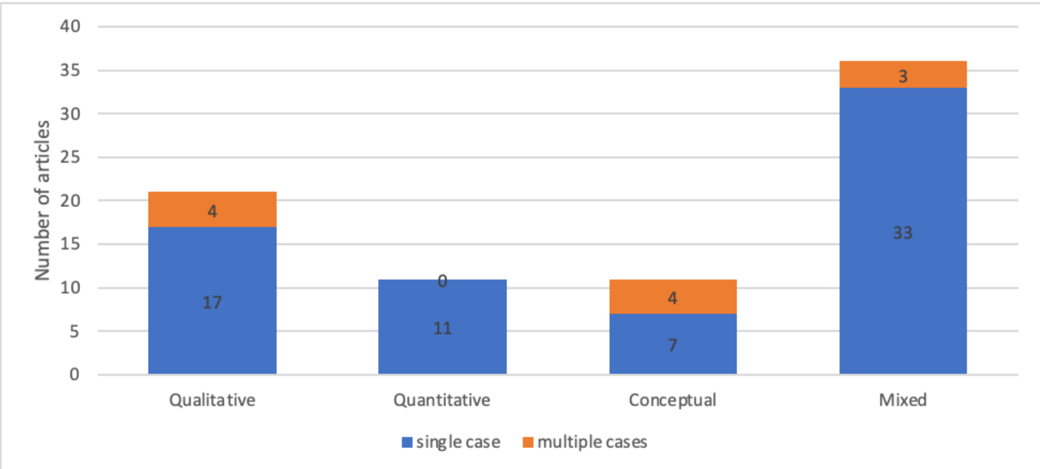

Figure 2.3: Articles by research method

Since case studies are always associated with certain contexts, some contexts trigger more in-depth analyses than others, leading to the question of which contexts are most studied and why (Cunningham et al., 2016). Figure 2.4 examines the location of the performed case studies. Out of the total 79 papers, 19 of these are based on China, followed by 11 studies on South Korea, 7 studies on Brazil, and 5 studies on the US, Japan, and the UK. Levels of studies vary from organizational, industrial, regional, and national. ‘International’ represents a case performing at a worldwide industrial level. ‘Europe’ indicates that the case is conducted in a European institution.

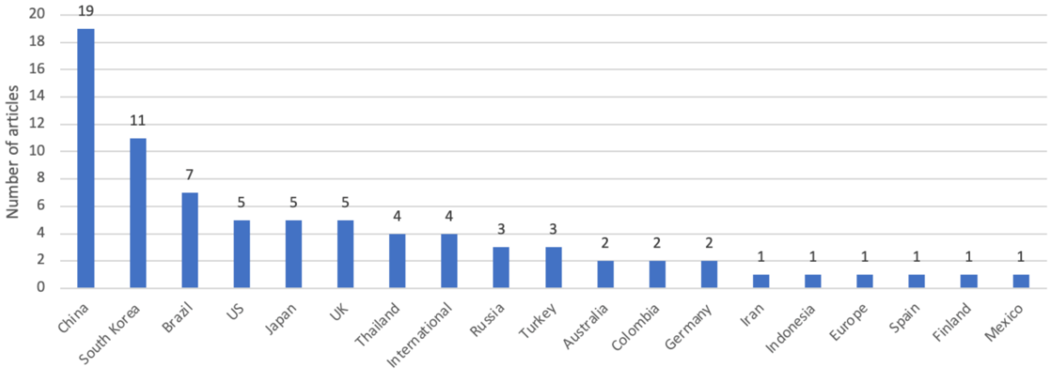

Figure 2.4: Articles by location of the performed case studies

Among all the articles, some perform multiple cases in one industrial sector while the others spread the cases throughout various sectors. We analyzed the case study or studies from a single sector in Figure 2.5. The sector in energy and renewable resources represents the largest percentage of cases studied in TRM (18 out of 79 studies), followed by the manufacturing sector (15 studies), the software and ICT (Information and Communication Technology) sector (10 studies), and the sector in knowledge-intensive services (9 studies).

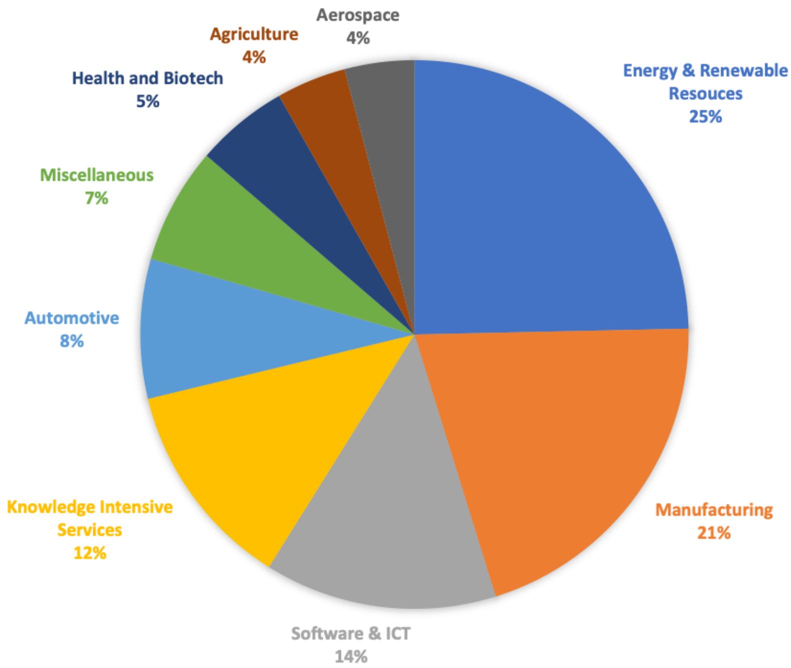

Figure 2.5: Percentage of articles by sector of the performed case studies

Note. **Energy & Renewable Resources** include: Bioenergy, Energy, Oil and gas, Solar cell, Utility, Wind power, Wind turbine; **Manufacturing** includes: CNC machine tool, Home security systems, Manufacturing, OLED, Semiconductor, Unmanned aerial vehicle, Underwater vehicle; **Software & ICT** include: Electronics, High tech, ICT, Nanotechnology, Power module, Software, Telecommunication; **Knowledge Intensive Services** include: Applied R&D center, Car sharing services, R&D into computer sciences, R&D into service operation, R&D into smart city, R&D into textile, Social banking, Testing, inspection, & certification services; **Health and Biotech** include: Health care, Pharmaceutical; **Miscellaneous** includes: Clothing industry, Media, Rail automation, Transport.

2.2.4 Summary of findings

Since the case study has been recognized as the main research method utilized in the field of TRM (Cheng et al., 2014), the current state of concepts and themes can be reflected and updated through the investigation of case studies. Previous literature reviews in TRM that focus on its concepts have identified three broad themes in the TRM research (Vatananan and Gerdsri, 2012; Gerdsri et al., 2013): 1) TRM development and implementation (i.e., the stages, activities, and key factors in implementing a technology roadmap); 2) tools supporting the TRM development (i.e., market and business analysis tools, technology analysis tools, and supporting tools);

and 3) TRM as a tool combined with other management tools for other purposes. Our research has also identified the 79 articles from these three themes (Table 2.2).

Table 2.2: Classification by the themes

Themes	**Literatures**
TRM development and implementation (43 studies)	Lee et al. (2013); Walsh (2004); Daim and Oliver (2008); Geum et al. (2011a); Gerdsri et al. (2009); Tierney et al. (2013); Li et al. (2015); Tuominen and Alqvist (2010); Zhang et al. (2014); Zhang et al. (2013); Jin et al. (2015); Geum et al. (2011b); Phaal et al. (2004); Gershman et al. (2016); Zhang et al. (2016c); Lee and Geum (2017); Li et al. (2016); Ghazinoory et al. (2017); Kameoka et al. (2003); Cowan (2013); Cheng et al. (2016); Lischka and Gemünden (2008); Haddad and Uriona Maldonado (2017); Fleury et al. (2006); Zhou et al. (2013); Kim et al. (2016); Son et al. (2017); Loyarte et al. (2014); Cresto Aleina et al. (2017); Cheng et al. (2014); Choomon et al. (2009); Kilkiş (2014); Contretas-Medina (2019); Kajikawa et al. (2011); Ibarra et al. (2014); Ibarra et al. (2013); Zhou et al. (2011); Hou et al. (2010); Feng et al. (2020); Daim et al. (2018); Pataki et al. (2010); Zhang et al. (2010); Gerdsri et al. (2010)
Tools supporting the TRM development (9 studies)	Hansen et al. (2016); Bloem da Silveira Junior et al. (2018); Daim et al. (2011); Kockan et al. (2010); Miao et al. (2020); Li and Sun (2014); Zhang et al. (2016a); Zhang et al. (2016b); Geum et al. (2013)

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Table 2.2 (*continued*)

Themes	Literatures
TRM as a tool supporting other models (27 studies)	Oliveira and Rozenfeld (2010); Huang et al. (2014); Vishnevskiy et al. (2015); Hussain et al. (2017); Lee et al. (2015); Hansen et al. (2016); Gonzalez-Salazar (2016); More et al. (2015); Lee et al. (2016); Jou and Yuan (2016); Yuan et al. (2012); Gindy et al. (2009); Sydow and Müller-Seitz (2020); Nakamura et al. (2010); Pearson et al. (2020); Son et al. (2019); Milshina and Vishnevskiy (2017); Liu et al. (2016); Mitake et al. (2020); Vinayavekhin and Phaal (2020); Silvello et al. (2020); Arianto and Surendro (2017); Wang et al. (2016); Geum et al. (2014); Vasconcellos et al. (2014); Igarashi (2015); Ateetanan and Shirahada (2016)

2.2.4.1 TRM development and implementation

The roadmapping literature suggests that the process consists of three different stages (Phaal et al., 2004a; Gerdsri et al., 2009; Lee et al., 2013; Daim et al., 2018). Although different pieces of literature put different names for those stages, Lee et al. (2013) compare those models and classify them into - preliminary activity, development of the TRM, and follow-up activity.

The preliminary stage aims to get an organization ready before implementing the TRM process. The activities include setting the objectives of the roadmap (Lee et al., 2013; Gerdsri et al., 2009), determining its boundaries and scope (Lee et al., 2013; Daim et al., 2018), defining an individual timetable (Lee et al., 2013), forming a working group for the roadmapping process (Lee et al., 2013; Gerdsri et al., 2009; Daim et al., 2018). The success of activities in this stage can be measured through the acceptance of the TRM concept among key stakeholders (Gerdsri et al., 2009), and the customization of the TRM process to meet organizational needs (Gerdsri et al., 2009; Fleury et al., 2006).

The objective of the development stage is to launch a full-scale TRM implementation. It emphasizes data collection and analysis (Gerdsri et al., 2009). A series of workshops are conducted to analyze collected data and graphically present the results in a roadmap form (Phaal et al., 2004a). The collection of data can be done both internally and externally. The benefits from the workshops are to share, transfer and create knowledge. A verification process is needed after the roadmap is developed, with the aim of making the roadmap more credible and valid (Lee et al., 2013). The measures for success in the development stage include the quality of content presented in a roadmap (Gerdsri et al., 2009) and the level of knowledge and experience sharing among different groups of participants (Gerdsri et al., 2009).

The follow-up stage is implemented to integrate the TRM process into ongoing business planning activities so that the roadmap can be constantly reviewed and updated in a timely manner. The activities include developing an execution plan (Lee et al., 2013), execution of the plan (Lee et al., 2013; Daim et al., 2018), review and updating the roadmap to keep it ‘alive’ (Phaal et al., 2004a; Lischka and Gemünden, 2008; Daim et al., 2018). This stage is vital since the TRM initiative is not a one-time effort but rather is exercised as an ongoing process (Kostoff and Schaller, 2001). The aim and desired result are the complete fusions of the TRM process into the organization so that the roadmapping process becomes a part of strategic business planning. The Hirose et al.’s (2020) maturity model, which directs organizations through the entire organizational implementation process, aids in sustainability and integration of the TRM process. Lee et al. (2013) point out that the establishment of an adequate software system is crucial to the continued use of roadmaps. The success in this stage can be measured through the strength of the linkage between technology roadmaps and a corporate strategic plan, and the continuation of TRM implementation (Gerdsri et al., 2009).

2.2.4.2 *Tools supporting the TRM development*

The use of modern tools and methods can contribute to the structure of the planning process and improve its effectiveness. A large number of papers study the tools that supporting TRM development. We use a similar approach as Vatananan and Gerdsri's (2012) study and group the roadmapping tools, according to their functionality, into market and business analysis tools, technology analysis tools, and supporting tools. Market and business analysis tools are applied in developing the top layer of a roadmap, by investigating new business ideas and market needs. Technology analysis tools are utilized to construct the bottom layer to predict, measure, and map capabilities like technologies, knowledge, and skills. Supporting tools assist the implementation of a TRM process by processing quantitative and qualitative data collected during workshops.

Table 2.3 classifies the literature according to the purpose of the study, with 9 studies of TRM tools focusing explicitly on the development of the tools. However, we find that many other papers in the TRM development or the integrated models also mentioned the use of advanced tools in their research; therefore, it is necessary to summarize these findings in Table 2.3.

Table 2.3: Tools utilized in the literature

Market and business analysis tools	- SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis (Jou and Yuan 2016; Arianto and Surendro 2017; Loyarte et al. 2014; Ibarra et al. 2013; Ibarra et al. 2014; Jou and Yuan 2016) - Business Model Canvas (BMC) (Arianto and Surendro 2017) - PESTEL (Political, Economic, Social, Technological, Legal, Environmental) analysis (Loyarte et al. 2014; Arianto and Surendro 2017) - MOST (Mission, Objectives, Strategy, Tactics) analysis (Arianto and Surendro 2017) - Resource Audit (Arianto and Surendro 2017) - Porter's Five Forces (Arianto and Surendro 2017)

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Table 2.3 (*continued*)

Technology analysis tools	- Bibliometrics (Li et al. 2016; Huang et al. 2014; Li and Sun 2014; Jin et al. 2015; Feng et al. 2020) - Patent analysis (Li et al. 2016; Jin et al. 2015; Huang et al. 2014; Yuan et al. 2012) - Network analysis (Nakamura et al. 2010; Li et al. 2016) - Fuzzy set (Zhang et al. 2016a; Zhang et al. 2016c) - TRIZ (Cresto Aleina et al. 2017; Zhang et al. 2013; Zhang et al. 2014; Feng et al. 2020) - Clustering method (Zhang et al. 2016b) - Technology-relationship-technology (TRT) semantic analysis (Miao et al. 2020) - Lifecycle analysis (LCA) (Zhou et al. 2011) - Technology readiness level (TRL) (Tierney et al. 2013; Pearson et al. 2020; Jou and Yuan 2016)
Supporting tools	- Quality function deployment (QFD) (Oliveira and Rozenfeld 2010; Jin et al. 2015; Geum et al. 2011a; Geum et al. 2011b; Ibarra et al. 2014) - Linking grid (Geum et al. 2011a; Geum et al. 2011b; Geum et al. 2014; Arianto and Surendro 2017) - Scenario planning (Hussain et al. 2017; Son et al. 2019; Zhou et al. 2011; Lee et al. 2015; Gerdsri and Kocaoglu 2007) - Delphi method (Lee et al. 2013; Kilkiş 2014; Bloem da Silveira Junior et al. 2018; Daim et al. 2011; Kockan et al. 2010) - Technology development envelope (TDE) (Daim et al. 2011; Kockan et al. 2010) - Cross-impact analysis (CIA) (Lee and Geum 2017) - Analytical hierarchy process (AHP) (Lee and Geum 2017; Li et al. 2015) - Decision matrix (Bloem da Silveira Junior et al. 2018) - Field anomaly relaxation (FAR) and Analytic network process (ANP) (Lee et al. 2016) - Design structure matrix (DSM) (Son et al, 2017) - Fuzzy Cognitive Map (Son et al. 2019)

2.2.4.3 TRM as a tool supporting other models

From the literature, the scope of technology roadmap is not limited to strategic planning but has been extended to a wide application, integrating other strategic processes such as new product development (Yuan et al., 2012; Kim et al., 2016; Oliveira and Rozenfeld, 2010; Jou and Yuan, 2016), product-service planning (Geum et al., 2011a; Geum et al., 2011b; Mitake et al., 2020), innovation management (Silvello et al., 2020; Liu et al., 2016; Igarashi, 2015; Vishnevskiy et al., 2015; Gershman et al., 2016; Haddad and Uriona Maldonado, 2017), and scenario planning (Geum et al., 2014; Hussain et al., 2017; Lee et al., 2015; Hansen et al., 2016; Milshina and Vishnevskiy, 2017).

The front-end of NPD comprises the activities that precede the formal development of new product projects, which defines the new products that should provide competitiveness and revenue for the business, making it a critical phase for NPD process performance. Oliveira and Rozenfeld (2010) present an Integrated Technology Roadmapping Portfolio Management (ITP) Method to support the development of front-end NPD activities based on integrating TRM and portfolio management (PPM). Jou and Yuan (2016) propose a new method that combines Crawford and Di Benedetto's model and Cooper's stage-gate model to strengthen the management of the fuzzy front-end in NPD. Yuan et al. (2012) develop an NPD model by using TRM and combining it with scenario planning and patent analysis.

Apart from NPD, there has been a research direction in TRM turning to the co-evolutionary of products and services, with the consideration of technological role in product-service integration. Geum et al. (2011a) suggest the integrated roadmap for product-service integration, with technology acting as a significant interface between products and services. Depending on the role of technology, the study proposes 6 types of product-service integrated roadmaps. Geum et al. (2011b) propose a customization framework that enables a firm to select the formats and methods of product-service roadmapping and provide practical guidance on its implications.

Mitake et al. (2020) propose a strategic planning method for product-service systems (PSS) development and implementation for sustainability by combining technology roadmap and transition scenarios.

TRM is also a useful tool to analyze innovation strategies, support and guide organizational development toward being an innovative organization. Chutivongse and Gerdsri (2019) create an assessment model to first assess the organizational status and identify areas for improvement, followed by the use of a roadmap to close gaps in order to raise the organization's level of innovativeness. For firms in the traditional industry, TRM helps the company better realize strategic transformation by making a technological plan, identifying strategic opportunities in the emerging industry, and providing advice about where the firm should exert efforts to enhance its technological innovation capabilities (Liu et al., 2016; Phaal et al., 2001a). Vishnevskiy et al. (2015) elaborate an approach of combining corporate foresight and integrated roadmapping for corporate innovation management. Gershman et al. (2016) study Russian state-owned enterprises (SOEs) for their development plans and the management tools in implementing innovation strategies. Haddad and Uriona Maldonado (2017) propose the use of the 'functions of innovation systems' as drivers within sectoral roadmaps.

Moreover, since the concept of scenario-based TRM integrates the flexibility of scenario planning together with the clarity of TRM and has been elaborated and incarnated (Postma and Liebl, 2005), Lee et al. (2015) propose a systematic approach to assessing the impacts of future changes on organizational plans by integrating sensitivity analysis into scenario-based TRM. Based on Lee et al.'s (2014) model, Hansen et al. (2016) develops a four-step scenario-based TRM, aimed to evaluate the relevance or importance of products and technologies as well as the robustness of the relevance against different future scenarios of market drivers. Hussain et al. (2017) present a 'scenario-driven roadmapping', which consists of 8 stages, and 'flex points' served as critical indicators of key changes in the environment.

2.2.5 Discussion

The findings are discussed in two aspects: 1) the strengths and limitations of the case study methods applied in TRM literature; and 2) emerging research topics identified through the themes.

2.2.5.1 Strengths and limitations of the case study method applied in TRM research

In spite of its diverse objectives, the case study method employed in TRM research is either for theory building or theory testing. First, an inductive approach is used for theory building, and two types of TRM case studies employing such approach. The first type of case study develops a common structure for a specific type of technology roadmap based on one case (e.g., Kim et al., 2016) or multiple cases (e.g., Gershman et al., 2016; Kameoka et al., 2003). Gershman et al. (2016) provide a good example of a multiple-case study in which three Russian state-owned enterprises (SOEs) are investigated in order to understand the methods they use to implement innovation strategies, and then a common structure of a technology roadmap is generated that serves as a strategic management tool for all other SOEs implementing innovation strategies. The second type of case study, which is more common in our sample, employs an inductive approach to develop a technology roadmap for planning one type of technology or product within one company, one region, or one industrial sector (e.g., Pearson et al., 2020; Contreas-Medina et al., 2019; Khanam and Daim, 2017). In addition, a deductive approach is typically used to validate the proposed roadmapping methodology (e.g. Tierney et al., 2013; Huang et al., 2014) or to simply demonstrate the applicability of the proposed method with some case examples for actual business cases (e.g., Geum, 2011a, 2011b). One good example is from Tierney et al. (2013), who first develop a Technology Landscaping technique to deal with new forms of innovation that include multiple root technologies, constraints, drivers and new business models, and then test the model using a case study of new pharmaceutical industry innovation.

The selection of cases is an important aspect of both theory building and testing in case studies. In our sample, 86% of studies utilize a single-case study approach, with the rest in a multiple-case approach. Although those single cases are likely to be replicated or extended to the proposed TRM process, the use of multiple cases can increase the credibility of the findings sharpen the empirical focus on the focal phenomenon, and enhance generalizability (Eisenhardt, 1989). We see opportunities in common process design (Eisenhardt, 2021) in which multiple cases are applied to test the same type of technology roadmap in different companies, industries, or economies, thus, to improve the transferability of the TRM process across settings. One good example is from Vinayavekhin and Phaal (2020), who create a Synchronization Assessment Framework for enhancing synergy in strategic planning by first conducting an in-depth case study, then examining the framework's broader applicability with four validating case studies and an experience survey. Geum et al. (2011b) is another example that validates the product-service TRM process with 6 case examples. On the other hand, for theory building, Eisenhardt (1989) suggests 4 to 10 cases are common and often work well. However, none of the studies in our sample employs such approach. Although Gershman et al. (2016) present a good example with 3 cases to develop a TRM framework for one type, we suggest that the future TRM theory or framework can be refined through the use of more cases. Moreover, some multiple-case tactics such as matched pair, racing, or polar types (Eisenhardt, 2021) are also encouraged to use in TRM development to gain a more comprehensive understanding of the phenomena.

Due to the fact that the traditional TRM method relies on the intuitive knowledge of participating experts that might be subjective and biased in some cases, an increasing use of multiple data collection methods is utilized in the investigated case studies. A number of case studies triangulate the qualitative results obtained through different methods, including interviews, qualitative questionnaires, observations, reports or literatures, to develop TRM method or framework (Contretas-Medina et al., 2019; Sydow and Müller-Seitz, 2020; Kim et al., 2016). Triangulation occurs when the evidence from several different sources converges on the same finding, increasing the reliability of the finding (Yin, 2015). Other cases blend qualitative methods and quantitative methods (such as bibliometrics, cross-impact analysis, and economic/climate/energy system models) in technology roadmap development (e.g., Huang et al., 2014; Li and Sun, 2014; Lee et al., 2013), as identified in Figure 2.3 where 45% of studies utilize a mixed-method approach. We see a clear trend of combining qualitative and quantitative methods in the TRM implementation, due to the utilization of different types of market and business, technology analysis, and supporting tools.

Last but not least, as for theory building or test, many case studies in the TRM literature are more like illustrated examples rather than traditional case studies in real settings. They miss the essence of inductive theory building in the analysis of the constant comparison between the theory and data (Glaser and Strauss, 1967), replication logic (Yin, 1984), and cross-case analysis (Eisenhardt, 1989). Most TRM case studies start with proposing a roadmap framework and then illustrate the process within a specific setting to show the usefulness of the framework. They lack an extensive iteration process between the emergent theory and data to create an increasing close fit between the two. In the case of TRM research, the emergent theory could be the specific type of TRM framework with expected performances, and the data could be the performances to be measured qualitatively or quantitatively. Constructs of the roadmap need to be tested and revised constantly until the performances reach the expectation. The lack of follow-up activities in TRM in current case studies is the main reason for missing this iterative process.

2.2.5.2 Emerging research topics in terms of themes

This section discusses the findings from the literature review and outlines a series of emerging research topics based on the themes that the current body of literature insufficiently addresses or has identified as a trend. The trends are the most significant frontiers in the advancement of TRM practices and the most significant contributions that TRM can bring to fulfill the company and society's needs. We suggest five emerging research topics, which are: 1) improving TRM practices; 2) development of scenario-based roadmaps; 3) development of social-needs-driven roadmaps; 4) TRM for agile innovation management; and 5) TRM for open innovation. Figure 2.6 summarizes the research opportunities in each line and the first articles to refer. The circle represents the next phase of TRM research should first focus on improving TRM practices as a general move, then further developing case studies based on four trends in terms of types and applications.

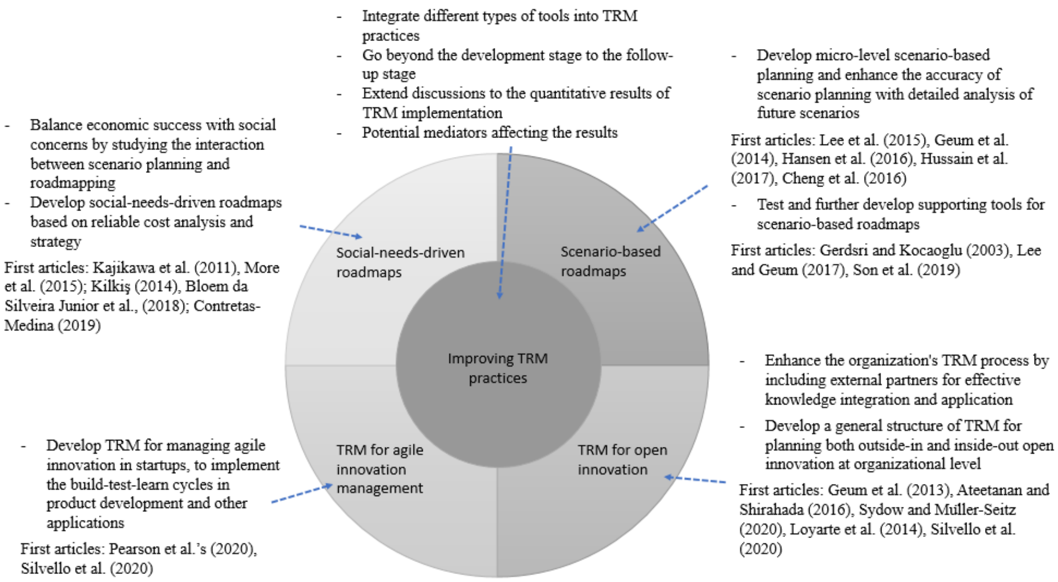

Figure 2.6: Emerging research topics and first articles to refer

Improving TRM practices. Integrating different tools in developing technology roadmaps can be the first tactic in improving TRM practices. From the literature, we have listed the tools supporting the TRM development in Table 2.3. Market and business analysis tools are used to identify market needs, get a better understanding of organizations' current state, define organizations' position in the future, and improve the planning process for business activities (Vatananan and Gerdsri, 2012; Arianto and Surendro, 2017). Technology analysis tools that contain IT techniques applied in scientific databases take active roles in data pre-processing and complement expert knowledge in result evaluation and refinement (Zhang et al., 2016c). Supporting tools such as linking grid and QFD matrix help in linking layers and sublayers of the roadmap and prioritizing the impact of the relations (Geum et al., 2011a; Jin et al., 2015); Delphi method is frequently utilized to obtain a reliable consensus of a group of experts (Lee et al., 2013; Mitchell, 1992; Yoon and Park, 2007). Each type of tool has different purposes of use. However, none of the studies has integrated all three kinds of tools into a single TRM practice. Identifying and applying the best tools in each phase of TRM, with the combination of qualitative and quantitative methodologies in market and technology forecasting, is a preferred approach for future TRM studies.

The second area of improving current research in TRM practices is to extend the activities to the follow-up stage. The majority of case studies in the literature focus on the preliminary stage and development stage of the roadmapping exercises by showing the usefulness of the roadmap based on the developed models. The discussion in the follow-up stage is normally omitted. However, activities in the follow-up stage including keeping the documents up to date and ensuring a periodical update of the roadmap are essential for the long-term strategic planning. Should the maintenance schedule for a roadmap be established? How long would be optimal? Or is it preferable to systematically monitor the status of a roadmap and take immediate action to review or revise it, rather than wait until the next periodical review schedule (Gerdsri et al., 2019)? There are also other issues such as the fact that technologies and ideas regarding new mission concepts are constantly evolving, which makes it hard to compile the updating roadmaps (Cresto Aleina et al., 2018). The subsequent TRM research should go beyond the explorative stage of TRM exercises to the monitoring and updating stage in order to find out the barriers and the corresponding solutions.

More importantly, insufficient records of follow-up activities also result in a lack of discussions in the quantitative results of implementation, that is, how does the implementation of TRM improve different performance dimensions. Along with the process, there is a lack of longitudinal evidence of how TRM informs and promotes business development, innovation creation, technology management, and strategic repositioning. For example, in the context of organizations, questions need to be answered, is the project complete within the agreed schedule? Is the measure cost-effective in all operative controlling systems? Are the financial targets of the activities reached? This step is essential because the results obtained from the quantitative analysis will be used in the feedback loop to calibrate and update the TRM process (Gonzalez-Salazar et al., 2016), putting in place a live TRM, as well as increasing the validity of the proposed roadmap. After a live TRM is achieved, it is also worthwhile to investigate potential mediators that affect the relationship between TRM practices and firm performance. Organizations and institutions can pay more attention to such mediating factors in improving the outcomes of TRM practice for the future.

Development of Scenario-based roadmaps. From 2003 to 2009, our literature shows the studies mainly focus on the TRM framework development and customization in different settings (e.g., Phaal et al., 2004a; Walsh, 2004; Daim and Oliver, 2008; Choomon et al., 2009). Since 2010, the study of role of uncertainty in decision-making has evolved. TRM has been more incorporating into emerging technology or industry for developing emerging technologies for business benefit, as well as assisting in transition and capturing dynamics of emerging paths. In doing so, scenario analysis is combined with TRM to study emerging markets and trends, identify weak signals, and formulate strategies and innovation policies to prepare for an uncertain future (e.g., Geum et al., 2014; Lee et al., 2015; Cheng et al., 2016; Hansen et al., 2016; Hussain et al., 2017; Son et al., 2019).

The benefit of scenario-based TRM is that it combines the flexibility of scenario planning with the clarity of TRM (Postma and Liebl, 2005). Scenario planning captures the full context of decisions and allows for the anticipation of a wide variety of potential changes, whereas TRM specifically addresses the strategies, directions, and tasks (Phaal et al., 2009). The key to success is a focus on the future coupled with good foresight based on flexible and adaptable mechanisms (Hines, 2003). Therefore, scenario-based TRM development in many applications will continue to be a trend in TRM research. The finding is consistent with Gordon et al.´s (2020) analysis of the evolution of foresight theory and practice.

The existing scenario-based roadmapping approaches are mainly used to monitor and analyze future changes for foresight at the macro level (i.e. at the national and industrial levels) because scenario planning is strong in terms of developing scenarios with a macro view of future changes (e.g., Zhou et al., 2011; Kajikawa et al., 2011; Geum et al., 2014; Hansen et al., 2016; Hussain et al., 2017; Son et al., 2019); while technology roadmapping is strong in terms of developing roadmaps with a micro view for action planning, but only a few studies focus on how to integrate the two at micro level (i.e. organizational level) for corporate planning (e.g., Lee et al. 2015; Cheng et al., 2016). Since companies are now confronted with greater uncertainty in the current business environment, future studies should focus more on supporting roadmapping through micro-level scenario planning and enhance the accuracy of scenario planning with detailed analysis of future scenarios.

Moreover, although our sample shows some practical guidance on how to build and integrate scenarios into roadmaps, unlike most other studies that primarily focused on developing simple scenarios to assist TRM or simply suggested the concept of multi-path roadmapping (Geum et al., 2014), these guidance demonstrates different approaches and is still at the explorative stage. For instance, in our sample, the 'scenario-driven roadmapping' process proposed by Hussain et al. (2017) uses a qualitative approach by following the full process of intuitive logic models; other studies (e.g. Hansen et al., 2016; Lee et al., 2015; Cheng et al., 2016) use a mixed qualitative and quantitative approach and add an extra step to evaluate the impacts of possible future scenarios; and Lee et al. (2016) and Son et al. (2019) use a pure quantitative approach. Future research should investigate the differences between them, improve each of them, and determine the optimal approach for different case settings.

Testing and further development of supporting tools for scenario-based roadmaps is another emerging research topic. Gerdsri and Kocaoglu (2007) suggest an integrated way to the development of scenario-based roadmaps by combining the Delphi method and hierarchical decision model to develop a Technology Development Envelope (TDE): a curve representing a series of technologies with maximum impact on company's competitiveness over time. Lee and Geum (2017) differentiate the internal scenario and external scenario, and apply two different methodologies for different layers of the TRM: Cross-impact analysis (CIA) for the market layer (i.e. a non-controllable external scenario) and the Analytical hierarchy process (AHP) for the technology and product layers (controllable internal scenarios). Son et al. (2019) utilize the Fuzzy Cognitive Map technique to analyze the causal relationships between factors for the quantitative scenario development. These studies are a good start for further improving scenario-based roadmaps by advancing supporting tools.

Development of social-needs-driven roadmaps. The sustainability issue is compelling nowadays. In the upcoming decades, diminishing resources and environmental problems will be the number one challenge against the improvements of society (Daim et al., 2011). Some mechanism is needed to unite various stakeholders in order to raise awareness and generate the accountability required to preserve and sustainably manage resources. Several papers have made the case that TRM is one of these mechanisms (e.g., Kajikawa et al., 2011; More et al., 2015; Kilkiş, 2014; Bloem da Silveira Junior et al., 2018; Contretas-Medina, 2019).

Although the companies are encouraged to consider sustainability aspects during TRM elaboration by balancing economic success with environmental and social concerns (Stead and Stead, 2000), the difficulty of developing such technology roadmap lies in the fact that it requires a social-needs-driven approach, which places more emphasis on the vision of the 'society to be' as the very basis of the roadmap (Kilkiş, 2014). Unlike market-pull or technology-push roadmaps, where the primary flow of the roadmapping idea descends from the market or the science and technology, future markets and trends are uncertain in a social-needs-driven roadmap (e.g., energy roadmap, agricultural roadmap). There is no clear driving force and motivation for each stakeholder in the current state (Yasunaga et al., 2009). In addition, the broad coverage of technologies for addressing sustainability issue and the high level of uncertainty in R&D make the development of social-needs-driven roadmaps more challenging. Therefore, in order to assess the impact of the focal technology, inputs from the other technology roadmaps that depend on the same energy system are needed (Kajikawa et al., 2011). Future cases must investigate how to integrate scenario planning and roadmapping by employing specific analyzing methods (e.g., risk analysis, sensitivity analysis) for developing social-needs-driven roadmaps. Moreover, due to the high-cost technological development, roadmapping based on reliable cost analysis and strategy to decrease it are also the remaining issues for social-needs-driven roadmaps. Overall, we anticipate that the successful experiences of future cases that take into account all these elements will provide us with guidelines for achieving sustainability in a TRM design.

TRM for agile innovation management. Existing case studies have identified TRM as a useful tool for large firms to analyze innovation strategies, help firms identify strategic opportunities in the emerging industry, and provide guidance on where the firm should focus its efforts to enhance its technological innovation capabilities (e.g., Vishnevskiy et al., 2015; Gershman et al., 2016; Igarashi, 2015; Liu et al., 2016); however, very little research is conducted in the context of start-ups. So, the question is how can TRM facilitate the innovation process of start-ups? Given the unique nature of start-ups, which are typically backed by investors who desire rapid development towards a commercial product and a return on investment, the agile innovation model that emphasizes building, testing, and learning iteratively on rapid cycles is the ideal innovation model for start-ups (Ries, 2011). TRM is an ideal instrument for fostering agile innovation. It enables start-ups to regularly evaluate and revise their medium- and long-term goals to ensure that near-term technological growth is in the direction of economic value. Thereby, a new research direction has emerged that integrates innovation management and TRM to create agile and adaptable organizations.

In our literature, Pearson et al. (2020) open up this avenue by applying TRM to a fusion energy start-up pursuing agile hardware development. The case study highlights the supportive role of TRM in the product planning phase, with the final roadmap outlining the innovation stages and the trajectory for commercialization. Future research can generalize the developed framework for other potential start-up applications. Moreover, since Pearson et al.'s (2020) study was unable to demonstrate the use of TRM in the follow-up stage, future research should go beyond the planning phase to show how the TRM process and the roadmap can be continuously updated to be aligned with build-test-learn cycles (i.e., to capture and manage any changes in company strategy as well as breakthroughs from technology development and experiments, and to inform the planning for the next development cycle), which will form a useful metric to measure agile innovation as a step-wise process during the development phase.

TRM for open innovation. Innovation has traditionally been discussed as a closed form (West and Gallagher, 2006). Since 2000, due to the progressive complexity of technologies and their inherent risks, innovation no longer takes place within single firms but has expanded beyond corporate boundaries (Chesbrough, 2003). Open innovation has proved to be an effective innovation management tool that allows firms to seek external ideas and partners as valuable resources for innovation and to reduce development costs and risks (Chesbrough and Crowther, 2006; Gassmann et al., 2010). Literature shows TRM has the potential to foster collaboration between organizations and to plan for open innovation.

Several papers have discussed how open innovation can be mastered at the network level in the TRM process (More et al., 2015; Sydow and Müller-Seitz, 2020; Tierney et al., 2013). In general, roadmaps produced at the sectoral level aim to offer a consensus view of the way forward and it is almost always collaborative among different firms, groups, and stakeholders. However, at the organizational level, open innovation faces apparent restrictions, and far less literature has presented case studies at this level. First, in contrast to the open nature of consortiums, roadmapping applications inside a company's strategic planning phase are led by a much more focused strategic framework (Phaal et al., 2004a). In addition, as the results of corporate strategy planning are often confidential, there may be risks associated with disclosing comprehensive project information to external supporters. However, the involvement of external partners (customers, suppliers, research institutes, competitors, etc.) in a TRM process can facilitate the effective inflow of knowledge into internal innovation activities, the integration of internal and external knowledge sources, and the successful application of knowledge during the planning phase. Future research should investigate methods for organizations to involve external partners in a TRM process without revealing any details of internal strategy, which could also result in increasing interface demands and a greater organization's capacity to receive and assess external impressions.

In addition, the development of a helpful roadmap structure that incorporates the open innovation paradigm can assist businesses in developing a comprehensive plan for attaining open innovation success. Geum et al. (2013) create a dual technology roadmap structure for planning outside-in open innovation, adding an extra partner layer and the planning of external knowledge in the already-existing layers of product, technology, and R&D. Future research could increase the value of TRM by building a system for planning both outside-in and inside-out open innovation, given the necessity of examining inside-out prospects for exploitation of internal ideas or knowledge from the beginning. Moreover, as partner selection is particularly crucial in open innovation (Geum et al., 2013), it is worthwhile to investigate guidelines or approaches that can enhance the partner selection and inclusion process.

Chapter 3
Challenges in Repsol Technology Lab and the reasons for implementing TRM

3.1 Repsol Technology Lab

Repsol is a global multi-energy company with the headquarter in Madrid, Spain. It is one of the world's largest private energy companies, developing Upstream (i.e., exploration, production) and Downstream (i.e., refining, marketing, liquefied petroleum gas and petrochemical) activities worldwide. Repsol Technology Lab (or Tech Lab) is the technology R&D center of Repsol. At present, Tech Lab employs more than 230 technicians and researchers (Repsol Technology Lab, 2024). Their responsibilities include the development of processes and products that ensure the continuous improvement of efficiency and technical and environmental quality. The technology R&D plans are developed based on open innovation and networking in alliances with technology centers, companies, and universities worldwide to seek sustainable solutions for a more efficient and competitive lower-carbon business. Since Repsol was the first company in the world that announced the commitment of net zero emissions by 2050 (Repsol, 2024). This corporate vision has been directing everyone in Tech Lab to work towards the creation of more sustainable energy through technology innovation.

3.2 Challenges in Tech Lab

Within the established operating model of Tech Lab, an innovation process called Demand Management is used to gather and plan innovative ideas based on internal business demands (i.e., Repsol's vertical business units). The objective of Demand

Management is to prioritize products to be developed for the next year. It consists of 5 stages - gathering, consolidation, prioritization, approval, and planning - with Figure 3.1 showing a simplified version of the Demand Management process in the year of 2021. First, in the early months each year, the scientists start gathering ideas and demands from business units. They remove duplicated or obsolete demands, and then refine list with business by confirming the impact estimation for each idea. At the end of this stage, a Long List of ideas and demands for the business are verified. In the consolidation stage, the scientists further refine those ideas, ensuring consistency across portfolios, following by translating those ideas into product proposals with risks and mitigation plans. They, then, select out 'must-do' products and 'could-do' products from the list of product proposals. From June, the third prioritization stage starts. All of the 'could-do' products are evaluated and scored and ranked accordingly in order to generate an aggregate list of products (or the Short List). August and September are the months for businesses' approval. During this stage, scientists further adjust, review, and iterate the list of products based on constrained budget. A consolidated final selection of products is decided at the end of this phase. Finally, from October to the end of the year, they plan for the implementation of these products to be undertaken for the next year.

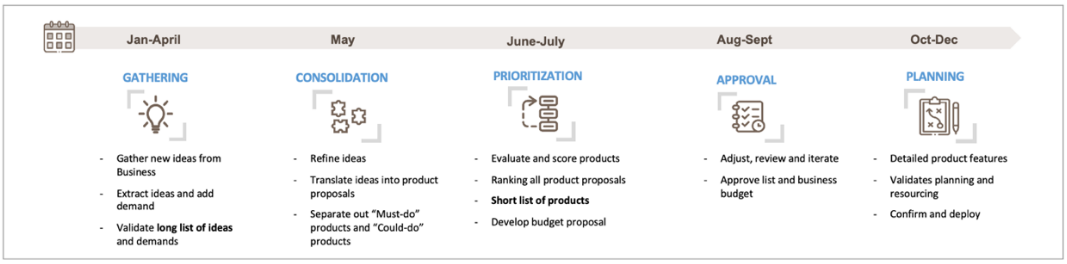

Figure 3.1: A simplified version of the Demand Management process in 2021

The problem with the prior operational model was that the Demand Management mainly focused on addressing *internal* demands, that is, maintaining and strengthening core businesses, with some new expansions but on a relatively short- and medium-term basis. Although foresight activities had been conducted sporadically among several groups, there was a lack of a structured foresight approach that can complement Demand management in order to explore and manage *external* demands in a systematic way. The product ideas derived from the external demands enable the company to develop new capabilities and think beyond the internal business needs; however, they typically need a much longer period of time to develop and a higher level of management and planning. The challenges associated with this problem include:

1) The identification of innovation foresight areas for Tech Lab. What are the next long-term sustainable innovation areas, outside of Repsol's current operating domain, that will allow integration with existing Repsol businesses and contribute to the company's global vision and strategy?

2) The development and synthesis of high-quality commercial and technological intelligence. When there is a need to expand the current technological development into a new area, how can we obtain a global view of the potential technological trajectories in that area, while simultaneously integrating market demands?

3) Strategic alignment and engagement among various research groups. Insufficient communication was observed among research groups of distinct disciplines. People from different groups were not aware of each other's activities. Multidiscipline collaboration is required when exploring new areas and formulating subsequent strategic plans for those areas.

All of these challenges can be categorized into the Explore and Create stage of the classical front-end innovation process (see Figure 3.2). To address these problems, it is necessary to employ a corporate foresight tool before the starting of the existing innovation process. The tool will complement the operating model and enable the completion of the front-end innovation process in Tech Lab.

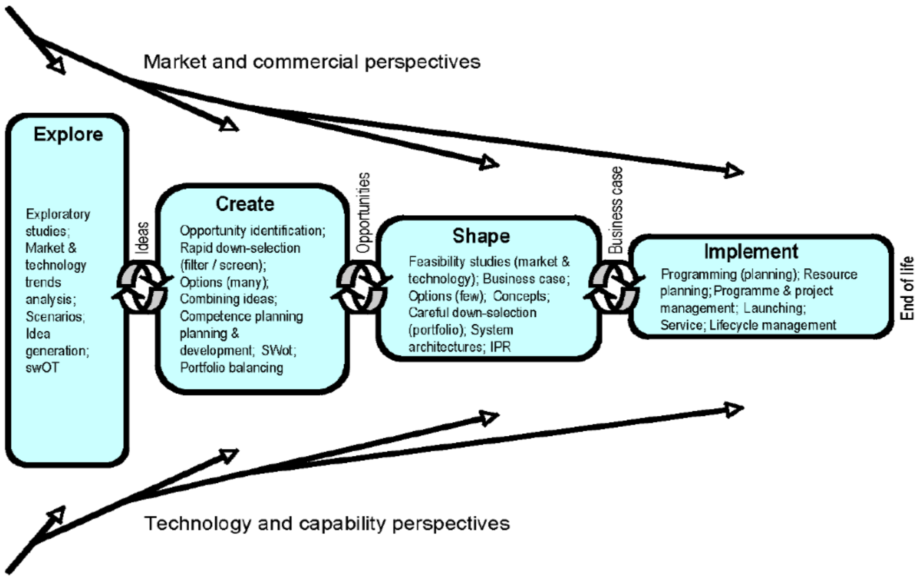

Figure 3.2: The classical front-end innovation process (retrieved from Phaal et al., 2008)

3.3 The reasons for implementing TRM in Tech Lab

TRM can be implemented to provide a systematic process in conducting corporate foresight and help Tech Lab overcome these challenges.

According to Rohrbeck et al. (2015), corporate foresight represents strategic foresight within organizational contexts, which is defined as "identifying, observing and interpreting factors that induce change, determining possible organization-specific implications, and triggering appropriate organizational responses" and it "involves multiple stakeholders and creates value through providing access to critical resources ahead of competition, preparing the organization for change, and permitting the organization to steer proactively towards a desired future" (Rohrbeck et al., 2015, p.2).

The first part of its definition emphasizes corporate foresight as an organizational ability to effectively analyze the environment, detect weak signals that may evolve into future opportunities or threats, and shape strategy that enables the company to explore new markets, products, and services (Slaughter, 1997; Tsoukas and Shepherd, 2004). It also indicates that corporate foresight is more than just supporting companies in anticipating the future; it must also be tightly integrated with the existing organizational processes and managerial systems (e.g., strategic planning and innovation management) in order to achieve flexibility and responsiveness to potential disruptions (Rohrbeck et al., 2015). Similar to the inverse situation, strategic planning alone lacks sensitivity to changes in the firm´s environment (Camillus and Datta, 1991) and the front-end innovation must be “strategically managed” due to its highly informal, knowledge-intensive and erratic nature (van den Ende et al., 2015, p. 483), the benefits of corporate foresight can only be realized through the creation of an integrated practice that plays an orchestrating role or by filling the gaps left by existing organizational functions. Companies need a practical management tool that can effectively integrate these activities and foster the creation of organizational routines that facilitate the development of future insights.

Roadmapping serves as such an integrated management tool. The inherent flexibility of TRM stems from its function as a central hub that integrates various tools specifically designed to address a variety of corporate challenges and activities (Kerr et al., 2017). While TRM has traditionally been considered as a “focal point” of corporate and organizational planning (Phaal et al., 2006), primarily serving strategic planning purposes, its functionality can be expanded by integrating it with other tools. The existing body of literature on corporate foresight and TRM has illustrated how roadmapping-based foresight activities can be achieved through the integration of traditional foresight tools (e.g., trend analysis, scenarios, expert opinions, bibliometrics, cross-impact analysis) and TRM, in which the forward-looking perspectives are first specified using foresight tools, and then roadmapping is structured with the explicit goal of realizing the key future perspectives (e.g., Vishnevskiy et al., 2015; Lee et al., 2016; Cheng et al., 2016; Geum et al., 2014).

In addition, its powerful underpinning framework of the roadmap supports the traditional foresight tools during the execution of foresight activities. In particular, the roadmap provides a “dynamic systems” framework with the dimensions of Why-What-How-When-Where-Who (Phaal and Muller, 2009; Kerr et al., 2019), in which 1) the “Why” represents trends, drivers, and needs at the top horizontal layer, where traditional strategic management techniques such as STEEPLE (i.e., social, technological, economic, environmental, political, legal, and ethical) can be incorporated, acting as a checklist that enables divergent thinking about the future; 2) the “How” represents technologies, resources and enablers at the bottom layer; 3) the middle-layer “What” represents innovative products and/or services, taking into account both the market-pull and technology-push dynamic to maximize innovation capacity (i.e., pulled by the top layer and pushed by the bottom layer) (Amer and Daim, 2010); 4) the “When” relates to the explicit dimension of time in roadmaps; and 5) the “Who” and “Where” are the aspects often embedded in the content of the roadmaps that must be specified for planning.

Such framework can be used as a guideline that serves as a research and diagnostic tool to explore emerging technology trajectories and innovation pathways (O’Sullivan et al., 2021). As a research tool, it is used to study the transition from one technological path to another and assess the factors which allow the emergence of winning technologies. As a diagnostic tool, it can be used to monitor and regulate the sufficiency, efficacy, and credibility of strategic foresight evidence (e.g., data, insights, perspectives) as it is gathered (Beeton, 2007). After the completion of the foresight activity, the resultant roadmap converges the outcomes, capturing a synthesized and integrated view of strategic innovation plans at a high level. As a result, by implementing roadmapping, Tech Lab will be able to perform an integrated activity in forecasting future trends, generating valuable innovative ideas, and strategizing for future actions.

In addition to the significance of an integrated corporate foresight activity in addressing uncertainties, the latter part of its definition puts emphasis on the creation of corporate foresight through the process of prospective sensemaking (Rohrbeck et al., 2015). Prospective sensemaking considers organizing as a process where individuals draw upon their prior experiences, engage in collective reflection, and interact continuously to develop shared cause maps that enable them to align their perspectives, goals, and courses of action (Weick, 1979; Rohrbeck et al., 2015). In addition, through prospective sensemaking, corporate foresight also sets the ground for an organizational learning process (Vecchiato, 2012; Boe-Lillegraven and Monterde, 2015) in which individuals exchange ideas and value with each other, stimulate creative thinking, and contribute to an intensive lateral and vertical communication for knowledge sharing (Foss et al., 2011) and a future-oriented organizational culture (Vishnevskiy et al., 2015).

Coincidentally, TRM is often implemented through workshops (Phaal et al., 2001a; 2007; Marinkovíc et al., 2022). In fact, the popularity of TRM can be attributed mainly to the communication and networking advantages that arise from the development, dissemination, and use of roadmaps as a common reference point, both during and after the workshop (Phaal et al., 2004b), making it an ideal tool for fostering and maintaining strategic conversations in organizations (Rohrbeck and Schwarz, 2013). In the workshop, cross-functional teams that include staff from different organizational functions and levels are involved to explore future prospects, share ideas and values from diverse perspectives, support each other and create knowledge in a collective manner (Kostoff and Schaller, 2001). In the meantime, external knowledge can be incorporated to balance the internal views and ensure the quality of data as an output (Gerdsri et al. 2010; Phaal et al., 2004b). TRM provides both an organizational learning and a knowledge management approach that offers the opportunities for internal and external knowledge to be combined and cross-fertilized, enables stakeholders to reach consensus on how to appropriately move forward or realize a vision given the particular circumstances of the situation being addressed (Kerr et al., 2019), and thereby leads to prospective sensemaking.

Therefore, TRM can be an ideal tool for Tech Lab that serves as a central tool for corporate foresight by offering: 1) a structured visual mapping method to support companies in analyzing possible futures and innovation pathways; 2) a workshop-based approach that facilitates the integration of diverse stakeholder perspectives; 3) a systematic process that harmonizes foresight activity with other organizational functions to investigate emerging markets and trends, identify weak signals, and formulate strategies and innovation policies for preparing an uncertain future.

Chapter 4
Research objectives and methodology

4.1 Research objectives

In spite of the necessity and potential benefits of utilizing TRM as a foresight tool for future-oriented decision-making, our literature review in TRM case studies (Ding and Ferrás Hernández, 2023) reveals that certain gaps must be addressed in order to fully reap these benefits.

The dynamic nature of our environment generates constant scientific, technological, societal, and political changes that significantly impact the development of businesses across diverse domains. An effective corporate foresight requires the implementation of a regular practice for maintaining a continuous review and update of the information base to assure robust analysis in later stages (Vishnevskiy et al., 2015). However, the existing body of literature on TRM has made limited efforts to investigate how TRM can be effectively implemented and integrated into organizational routine to support ongoing organizational decision-makings (Vatananan and Gerdsri, 2012; Kerr et al., 2019; Hirose et al., 2023). Our literature review in TRM case studies has revealed that the current case studies focus heavily on the design and development of roadmap models with a descriptive outline of roadmapping approach being implemented on the preliminary and development stages, utilizing either a deductive or inductive approach (e.g., Geum et al., 2011; Tierney et al., 2013; Huang et al., 2012; Vishnevskiy et al., 2015), while the information on how to ensure a periodical update of the roadmap (i.e., the follow-up stage activities) and how the TRM activities can be combined with other management activities is normally omitted. This results in an overemphasis of the TRM methodology research on the development of the roadmap framework, although equally important, while overlooking the significant value of the roadmapping process in terms of communication, organizational learning, and the establishment of a sustainable practice within the organization.

Furthermore, insufficient record of the follow-up activity has resulted in a dearth of longitudinal evidence regarding the level of performance that could be attained by the implementation of roadmapping. Previous research on TRM has identified several key underlying factors that contribute to the successful implementation of organizational roadmapping in general. Gerdsri et al. (2010), for example, identify three success factors as "people" (i.e., workshop participants and key stakeholders), "processes" (i.e., roadmapping process design and implementation and integration), and "data" (i.e., management and alignment of strategic contents on roadmaps). In relation to the outcomes, the current studies tend to adopt an approach that focus exclusively on quantifying the process-related outcome of roadmapping activity in terms of usability, usefulness and functionality (e.g., Farrukh and Holgado, 2020). These insights offer valuable information regarding the key elements that require attention during the implementation process and the possible process measurement. However, given the wide range of applications that TRM could serve and the adaptable nature of the methodology, the key performance factor related to business (as opposed to the process) and the success factors that lead to a sustainable organizational roadmapping process are also worth exploring and should be discussed separately according to the specific objectives of utilizing this tool.

Therefore, by taking into account both the interests of Tech Lab and the state art of the TRM literature, my research objectives are fourfold:

1. Develop a customized roadmapping methodology for Tech Lab to improve its foresight and strategic planning process.

2. Conduct an action research study (30-month timespan: 2021.07 – 2023.12) in Tech Lab, extending the research to the follow-up stage (i.e., the extent to which roadmapping is integrated into the existing management process).

3. Measure both qualitatively and quantitatively the real performance dimensions or value contributions for Tech Lab by implementing and sustaining the methodology.

4. Analyze the challenges during the process, as well as the success factors that could lead to a sustainable roadmapping process in an organization.

4.2 Methodology

Action research stands out as an ideal research method due to several reasons. Firstly, action research is a research methodology that employs a scientific approach to study the resolution of social or organizational issues in collaboration individuals who directly encounter these issues (Susman and Evered, 1978; Eden and Huxham, 1996). It can be seen as a variant of case research; however, the researcher is not an independent observer (i.e., an outsider researcher) and the goal is not only about creating universal knowledge (Westbrook, 1995). Instead, it needs the researcher to get involved into the practitioner’s world (the “action” aspect) and create knowledge or theory about the action (the “research” aspect) (Eden and Huxham, 1996). Coincidentally, the nature of undertaking an industrial PhD requires the researcher to play an immersive role (i.e., an insider researcher), actively collaborate with the company on real-life management challenges, and provide solutions to them.

Secondly, roadmapping is an established management tool and requires a practice-based lens that examines and reflects upon its associated activities and processes (Kerr et al., 2019), which implies that knowledge is to a large extent embedded in practice. In contrast to the traditional view of scientific enquiry (i.e., the positivist and interpretivist research) which tend to see knowledge as a free-standing unit residing "out there" in books and databases, knowledge embedded in practical management tools is not static and complete, but evolving in a live and constant process of development as new understanding emerge (McNiff and Whitehead, 2002). It can be argued that it is only through practice that the knowledge of management tools like roadmapping may be acquired and transferred, therefore, making action research an appropriate approach.

Moreover, action research is inherently concerned with facilitating change (Coughlan and Coghlan, 2002; Puhakainen and Siponen, 2010), and change management is also traditionally applied to assist an organization in establishing the roadmapping implementation plan (Gerdsri, 2013; Phaal et al., 2006). Action research is a sequence of events that comprises a cyclical process of planning, taking action, evaluating the action, leading to further planning and so on (McNiff and Whitehead, 2002). It is, therefore, favorable to utilize this approach for the implementation, evaluation, and improvement of a continuous roadmapping practice in an organization. This approach offers an ideal means to inform how a large system recognizes the need for change, articulates a desired outcome from the change and actively plans and implements how to achieve that desired condition (Coughlan and Coghlan, 2002). The outcome of research can provide not only solutions to the problem, but also important learning, and a contribution to scientific knowledge and theory in the field of roadmapping.

4.3 Data collection and analysis

Over a span of 30 months (2021.07 – 2023.12), I played an immersive role in Tech Lab, collaborating with practitioners in one roadmapping project. The longitudinal design of the study facilitates the compliance with the principle of a cyclical process of action research (Coughlan and Coghlan, 2002), in which I actively participated as a project champion, assisting Tech Lab in identifying the problem, proposing the solution to the problem, planning and executing to achieve a continuous improvement of the approach. Various data gathering methods, such as participant observations, archival documentation, workshops, and meetings, were applied in the different phases of the research, with an ultimate goal of developing a practical and efficient method for roadmapping activity within Tech Lab.

At the outset of the action research, the free and unlimited access of company documents and archival data provides me with a foundational understanding of the company environment, the conditions of business, and the structure and dynamics of operating systems. In addition, my perception of the company's reality was further strengthened through training sessions, meetings, and informal conversations with different project members within the organization. All of this information allowed me to diagnose and identify the current problem in the company.

During the execution phase, I worked as a champion in the project team, responsible for arranging a variety of project meetings targeted at different types of audiences (e.g., top management team, range managers, workshop participants) for explaining and following up on the project, organizing and facilitating a series of roadmapping workshops, analyzing results, collecting feedback, and so on. During this time, feedback was gathered not only from formal workshop events or meetings, but also from emails and informal meetings (e.g., during the lunch or break). All these qualitative data were collected and analyzed through a process of reflection and iteration between the data, the literature, and the company (Dubois and Gadde, 2002; Wouters, 2009), with the aim of enhancing the company's foresight and strategic planning process through action research.

Following the completion of two cycles of the action research, the innovation outcomes (i.e., the quantitive measure of results) were analyzed to show the actual realization of the benefits from the implementation of roadmapping in Tech Lab. These include: 1) the number of foresight (or future) topics derived from the roadmapping workshops that are out of the scope of the current strategy; and 2) the number of new product ideas that were linked with these future topics proposed in the subsequent Demand Management process. The first measure was used to prove the effectiveness of the roadmapping activity, and the second measure was applied to check the overall integration level of roadmapping with the existing operating model. Additionally, other value contributions of the process (e.g., strategy-related and organizational-related outcomes) and the challenges were discussed and analyzed qualitatively based on the feedback and comments from the participants, as well as from some other organizational events where the process was discussed. For reasons of confidentiality, the details of the output of the exercise (e.g., the list of key trends and drivers, future topics, strategic content on the roadmaps) are omitted in the thesis.

Chapter 5
Action research study in Tech Lab

The action research lasted a period of 30 months and was divided into two research cycles, illustrated in Figure 5.1. The initial research cycle at Tech Lab encompassed the adoption of a standardized S-Plan roadmapping process (Phaal et al., 2007) for the purpose of corporate foresight, spanning from July 2021 to July 2022. The second phase of the research cycle aimed to adapt the standardized process in order to seamlessly incorporate it into the pre-existing organizational process. It was started in August 2022 and ended in December 2023.

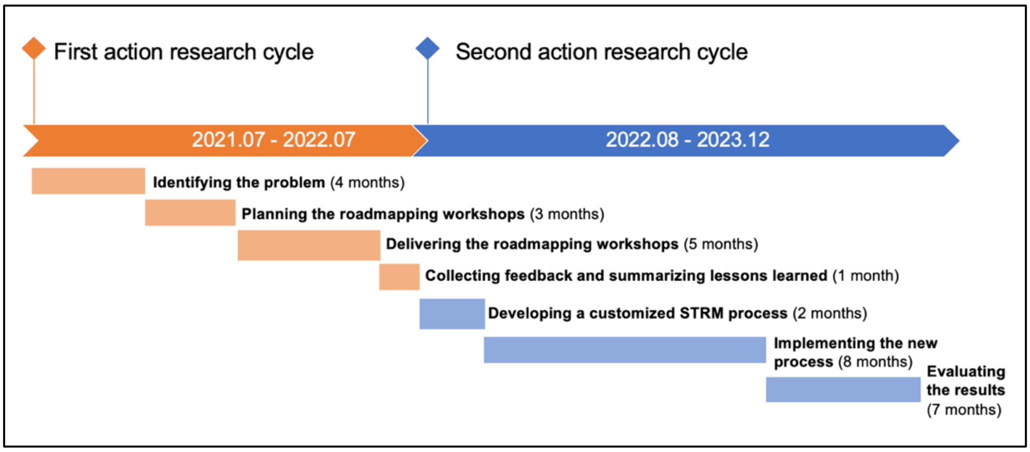

Figure 5.1: The timeline of the action research

5.1 The first action research cycle: Testing S-Plan roadmapping workshops in Tech Lab

The first action research cycle at Tech Lab involved the implementation of a foresight process through the utilization of a standardized S-Plan roadmapping procedure. In compliance with the principles of action research (Coughlan and Coghlan, 2002;

Puhakainen and Siponen, 2010), the first research cycle was carried out in the following four phases: (1) identifying the problem, (2) planning the roadmapping workshops, (3) conducting the roadmapping workshops, and (4) collecting feedback and summarizing lessons learned.

5.1.1 Identifying the problem

The first step was to identify the problem in the existing operating system. After a series of trainings, meetings, and conversations with the co-workers in the company, I had a clear understanding of the operating system of Tech Lab and a couple of challenges the employees were facing. An explanation on the prior operating model of Demand Management and a summary of challenges in Tech Lab are stated in Chapter 3. In summary, Tech Lab was looking for a foresight process, as one step ahead of Demand Management, for complementing the established innovation process. And at the same time, this process could improve the strategic alignment and communication among various research groups to allow multidiscipline collaboration when exploring new areas and formulating subsequent strategic plans for those areas.

5.1.2 Planning the roadmapping workshops

After several rounds of discussion, the management team reached a consensus on the scope and objective of implementing roadmapping and decided to allocate resources to support the roadmapping activity. Even though the relevant methodology and similar case studies were found in the literature, considering the internal personnel's limited experience, the management team decided to seek assistance from a consultancy for the first trail implementation. We reached out to IfM Engage given their extensive experience in the practice of roadmapping. IfM Engage is a consulting firm that is a wholly owned subsidiary of University of Cambridge in the UK. Following the discussion, we decided to implement the S-Plan ("S" stands for "Strategic") roadmapping methodology (Phaal et al., 2007) for the first trial. It is ideally suited for addressing the challenges in Tech Lab since this fast-start approach is designed to support general strategic appraisal, and the identification and exploration of new strategic, innovation, and business opportunities.

In addition, a roadmapping core team was formed inside Tech Lab that consisted of me and three senior managers (one senior manager of operating model and two senior range managers). The formation of the core team is essential to the success of the process (Gerdsri et al., 2009). Inside the core team, I worked as a champion to manage project details, one manager as a project leader to plan and supervise the project, and two other managers to support the communication inside and outside the company. The project was also sponsored by one director from the top management team to ensure the realization of its success.

Following the establishment of the core team, the workshops were planned with a list of activities that included communicating the aims and scopes of the initiative to various groups inside Tech Lab, naming a list of workshop participants, carrying out the project kick-off meeting, assigning pre-work to the participants, selecting external experts and conducting interview with them, analyzing pre-work and expert interviews, and planning the agenda, schedule and logistics for the workshops.

5.1.3 Delivering the roadmapping workshops

The roadmapping workshop was delivered in two parts. The first part consisted of a five-day strategic workshop facilitated by IfM Engage in the late February in 2022. It was designed based on the S-Plan fast-start workshop. The S-Plan process, which is originally configured for a one-day workshop, consists of four fundamental tasks (Phaal et al., 2007): 1) generate a strategic 'landscape' through a structured brainstorm using the roadmapping framework; 2) explore and identify 'landmarks' (i.e., prioritized opportunities); 3) deep dive on 'landmarks' through topic roadmapping; 4) develop a roadmap to agree a way forward. Figure 5.2 depicts the generic underlying structure to the S-Plan process sequences (Kerr et al., 2019). Fundamentally, roadmapping is deployed at two distinct levels (i.e., landscape and landmark) with each serving its own purpose (i.e., structured brainstorm versus deep dive). Due to the restrictions imposed by COVID in early 2022, we had to divide the standard one-day workshop into five days, combining on-site and online workshops to complete all activities. Figure 5.3 summarizes the workshop procedure and activities for strategic roadmapping in Tech Lab.

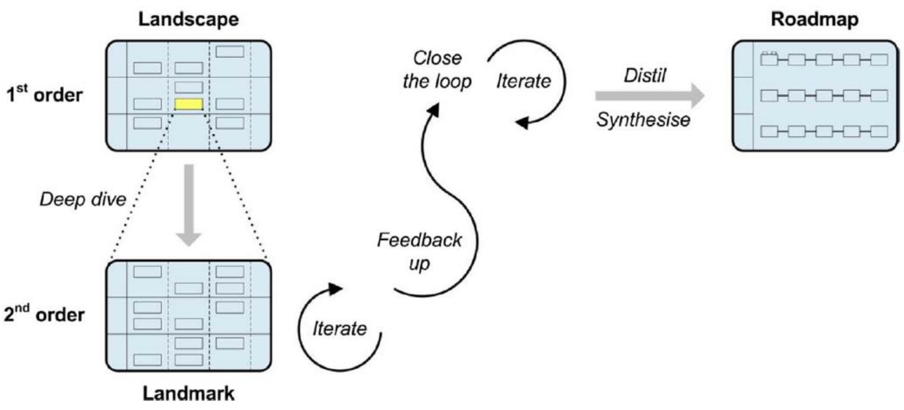

Figure 5.2: The underlying structure of the S-Plan process (retrieved from Kerr et al. 2019)

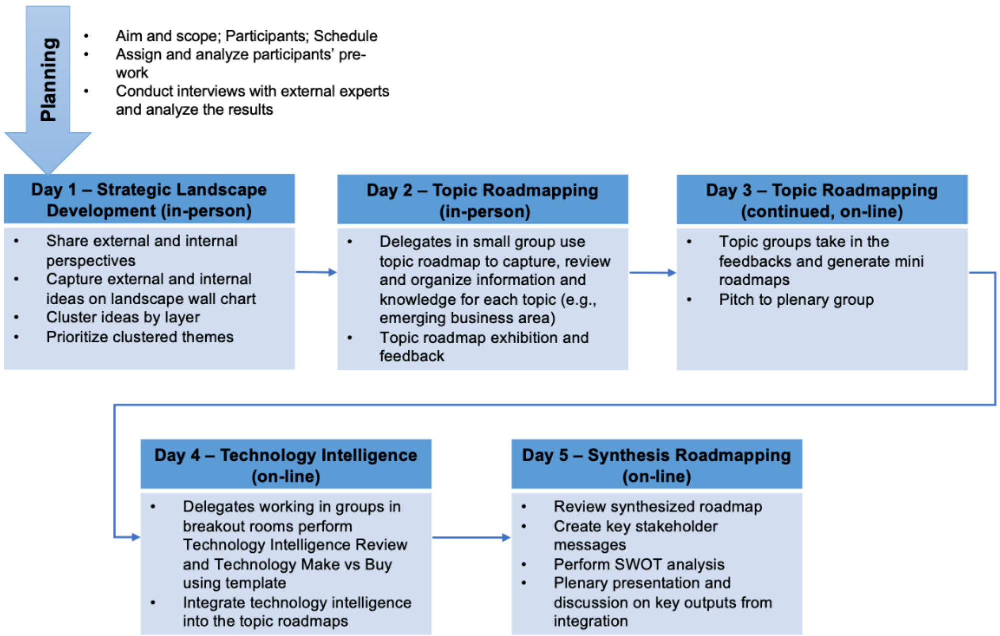

Figure 5.3: Process and activities of the strategic roadmapping workshop in Tech Lab

First, the strategic landscape development was performed on Day 1. It utilized a structured brainstorming approach using a roadmapping framework (i.e., the landscape, see Figure 2.1), where a multifunctional group of over 30 participants shared, clustered, and prioritized their internal and external ideas regarding the key trends and drivers, product and service solutions in response, and the key technologies and capabilities required to support these innovations. At the conclusion of Day 1, eight focal innovative areas (i.e., the landmarks) with the greatest potential were identified. On Day 2 and 3, topic roadmapping activity was carried out to provide deep dive analyses of these focal innovation areas. Using a topic roadmap template, delegates worked in small groups to capture, review, and organize information and knowledge for each focal innovation area. The topic roadmap template provides a common structure in order to gain a more consistent output against the parallel topics being explored. The layout of the topic roadmap template provides a supporting mechanism to explore the nature of each focal innovation areas in more detail, articulate possible routes forward and to synthesize the main components of a mini-business case and elevator pitch (Kerr et al., 2019). On Day 4, technology intelligence was performed. A detailed Make-Buy-Partner analysis of key technology requirements in each focal area could highlight the research gaps and improve the understanding on the required resources and capabilities along the development stage. Thus, on Day 4, key technologies in the focal topics were identified and technology intelligence was then conducted using additional technology tools including Technology Intelligence (Kerr and Phaal, 2018) and Technology Make vs Buy. The information obtained from the analysis was then incorporated into the topic roadmaps. Finally, on Day 5, all of the topic roadmaps were integrated into a final synthesized roadmap for delegates to review and provide feedback.

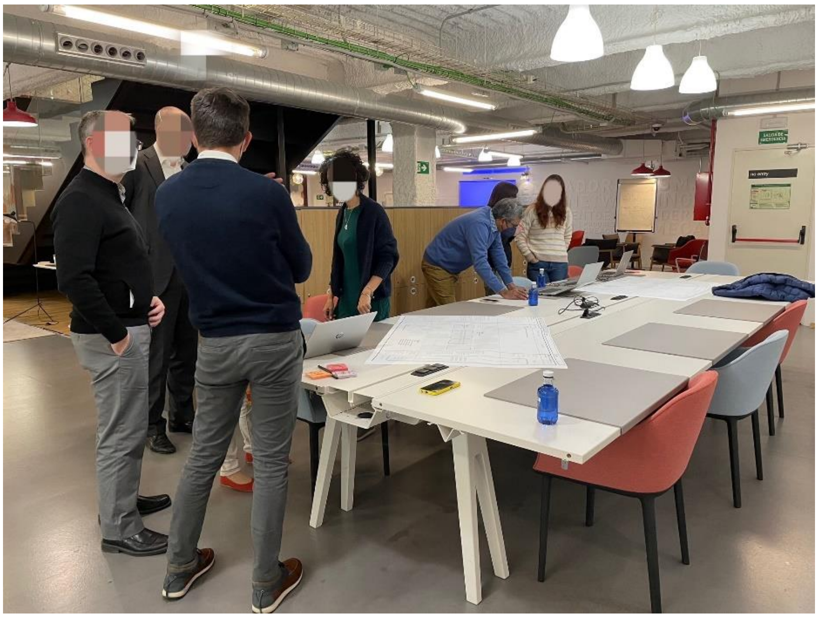

Figure 5.4: Delegates performing topic roadmapping activity in the workshop[2]

Because the strategic landscape workshop focused on the identification of new innovation areas, whereas the output was a synthesis of Tech Lab's strategic plan, the management team requested the topic roadmapping activity be repeated with the existing range strategies in order to complete the output with both current business and foresight areas. In the second part, offline topic roadmapping activities were conducted within five ranges. This time, with the support from IfM Engage, the core team was trained to understand the analysis steps and required tools used for developing a roadmap. In June 2022, the new synthesis roadmapping workshop was physically held in Tech Lab, where 13 strategic topics (including both current and new strategic topics) were presented and reviewed by workshop participants and the top management team, and the final strategic roadmap for Tech Lab was produced.

[2] The participants' faces have been blurred based on the General Data Protection Regulation (GDPR).

5.1.4 Collecting feedback and summarizing lessons learned

Throughout the roadmapping exercise, we constantly received feedback from the participants. Following the completion of the first research cycle, a total of 78 feedback responses were received. We analyzed all of them, also including the core team's own reflections, and summarized some important lessons learned from the overall experience.

The feedback covered a wide range of issues, including the workshop process design, activity design, roadmapping methodology, facilitation, resource and planning, and crisis management. Out of the 78 feedback responses, 14 (17.9%) were positive while the remaining 64 (82.1%) were regarded as suggestions for improvement. Several key messages concerning the issues to be addressed include:

1) Methodology must be improved, for example, by clearly defining "products" and "technologies", and by developing clearer ranking criteria for value propositions.

2) More visionary ideas need to be encouraged.

3) There should be a longer interval between workshops, with clear pre-work instructions for better preparation.

4) Participants to various types of workshops should be selected based on their expertise.

5) Roadmapping should be applied to the existing ranges, with topics from the existing ranges merged with foresight topics from the workshop to achieve strategic alignment.

6) The foresight workshop should begin with a clear picture of current strategy.

7) Spanish is a better workshop language for Tech Lab than English, and in-person workshops are better than online ones for creative activities.

5.2 The second action research cycle: Developing and executing Tech Lab´s own STRM process

While the first action research cycle focused on testing the standardized S-Plan roadmapping workshops to be used as a foresight process at Tech Lab, the second action research cycle aimed to refine and customize the process so that it could be integrated with the existing organizational process and become an organizational routine. The feedback and lessons learned from the first cycle of action were taken in to enhance the process. In contrast to the first cycle, which was primarily guided by theory, the second cycle addressed issues prompted by practice (Puhakainen and Siponen, 2010). Three phases comprised the second cycle: (1) developing a customized STRM process, (2) implementing the new process, and (3) evaluating the results.

5.2.1 Developing a customized STRM process

By taking into account both the reference S-Plan process and the lessons learned from the first trail, the core team developed a customized Strategic Technology Roadmapping (STRM) process. The new process was named after its intention to combine the functions of exploring and identifying long-term strategic opportunities, analyzing the key technology and other capability requirements within these opportunities, and aligning the current strategies across different ranges to develop an integrated roadmap indicating the Tech Lab´s short-, mid-, and long-term plans of activities. Both the “strategic” and “technology” aspects of utilizing the roadmapping methodology were emphasized to create a new terminology – Strategic Technology Roadmapping (STRM) – for its internal use within Tech Lab. This new process was reviewed and approved by the top management in September 2022.

5.2.1.1 Definition of STRM and its objectives

In short, the STRM process is a process that integrates corporate foresight and strategic planning process in order to establish a structured approach for defining the short-, mid- and long-term roadmap of activities in Tech Lab. It is designed to better suit the working environment of Tech Lab and integrate with the existing management process. It operates as a precursor to the existing Demand Management process, with four objectives:

1) Complementing Demand Management to develop a comprehensive front-end innovation process.

   With STRM as the first step, the innovation process starts with identifying the global and industrial trends and drivers that could impact on our business, from that defining a list of key topics for Tech Lab, including both future and current strategy topics, to define the business-level strategic short-, mid- and long-term plans for Tech Lab. Then, it proceeds down one level to the Demand Management process to define new product ideas based on this plan, before beginning the more serious stage of product development.

2) Improving strategic alignment and engagement among all ranges.

   Each range must collaborate in order to establish this strategy. It requires sharing a review of the current range strategies, engaging internal experts from all functions to work together in order to fully exploit internal knowledge.

3) Stimulating new ideas through combination of internal intelligence with external insights.

   Integrating external knowledge into the foresight activity enables the expansion of internal knowledge boundaries, fostering creative thinking, offering new problem-solving approaches, as well as ensuring the quality of the data contained in the final roadmap.

4) Contributing to the definition of corporate strategy.

The STRM process is designed to align with the corporate strategy process, with its outcomes directly contributing to the creation of the corporate strategy (i.e., Repsol strategy at the corporate level).

5.2.1.2 Five steps of STRM

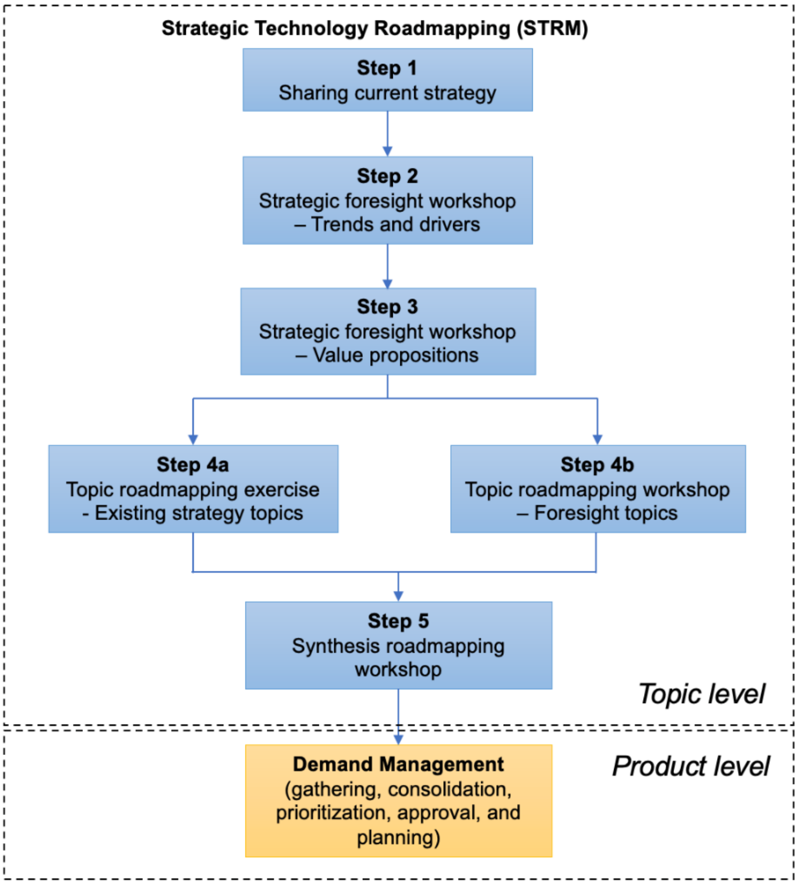

Figure 5.5: STRM process engaged with the existing organizational system

Figure 5.5 illustrates the five-step STRM process. Given the broad scope of research being conducted in Tech Lab and the need to answer the call for starting the foresight process “with a clear picture of current strategy”, **Step 1** consists of a workshop, which we call the “Sharing Day” workshop, where managers from various groups share their current strategies. In order to facilitate explanation of the key points, all strategies are required to present in the same format by using the topic roadmap. This workshop serves as the starting point in the corporate foresight and innovation process. It allows scientists and researchers to have a clear understanding about the areas other groups are working on and prevents future innovation proposals from duplicating efforts.

After establishing a clear understanding of the current state, strategic foresight workshop is conducted with the objective of defining a list of foresight innovation topics (or future topics) for Tech Lab. It has two steps. To begin, **Step 2** involves the first part to analyze the external trends and drivers by looking into the future. In this workshop, cross-functional teams comprised of managers and key technical and marketing personnel from various organizational functions are involved to share their opinions. With a focus on the top "Why" layer of the strategic landscape, the STEEPLE structure is used to examine external trends and drivers that may have an influence on the business. In addition, since the integration of external knowledge with internal knowledge is crucial in order to prevent organization's cognitive myopia (Levinthal and March, 1993), external data from various sources (e.g., expert interviews, external analyses and surveys) is collected and analyzed ahead of time and shared within the workshop setting. During the workshop, participants are requested to analyze both their own ideas and external ideas, and then prioritize the trends and drivers that are likely to have the greatest potential impact.

Step 3 continues with the strategic foresight workshop but moves on to the middle “What” layer of the landscape, which is centered on the exploration of value proposition ideas or tangible opportunities in relation to the pre-defined trends and drivers. Same as the prior workshop, the incorporation of external knowledge is required to provide stimuli for creative thinking. In this workshop, participants are asked to brainstorm and refine their ideas, share their most innovative ideas, and cluster the ideas into themes to create foresight innovation topics. In order to facilitate the prioritization of these topics, participants are then divided into groups according to their areas of expertise to provide a precise definition of the particular foresight topic and conduct an initial evaluation of its potential opportunities, such as market attractiveness, synergy opportunities, and future potential. Following that, utilizing the initial group topic assessment as a guide, each participant ranks and prioritizes the topics according to their own understanding and evaluation of the topic. Ultimately, all participants arrive at a consensus regarding the topics that offer the most potential for advancement prior to further exploration. These topics consist of future topics that are out of the scope of our current range strategy, and the product in those topics will be commercialized or available in no less than three to five years, even beyond.

The topic roadmapping activity in **Step 4** is conducted in two parallel lines. In one line, relevant technical experts are selected and invited to the topic roadmapping workshop to further investigate the prioritized future topics. Vertical business ranges, on the other hand, conduct off-line roadmapping exercise inside their ranges for the key topics in their strategy. At this stage, the capabilities and key enabling technologies (the “How” information) are further examined thoroughly for the topic in question. In the meanwhile, by incorporating the “Why” information determined in Step 2, the innovation pathways of each topic should have an explicit series of steps for their direction of travel and an initial sense of a storyline that reflects the nature of the push (i.e., enablers) versus pull (i.e., drivers) dynamics (Kerr et al., 2019). This approach differs from the S-Plan method in which the push-pull dynamics of a single product idea is initially considered and contrast against each other across the landscape, and then analyze again when developing topics. The rationale behind this adjustment is that, for long-term oriented foresight topics, the ultimate feasibility is extremely difficult to estimate; therefore, if the identified opportunity for such a topic is substantial, future feasibility analyses for a particular project can be conducted by taking into account the time and financial resources necessary to advance it to the next decision point (Mitchell et al., 2022). Thus, the topic feasibility analysis at this stage need only be carried out once substantial opportunities have been found, with the purpose to offer an overview of the topic know-how (e.g., capabilities, key enabling technologies, competitors, and potential collaboration parties) that may support future project proposals.

Following the development of both strategy and foresight topics, the synthesis roadmapping workshop represents the last step (**Step 5**) of the STRM process. In this workshop, all topic groups are required to present the development plan for their topic. The topics are, then, brought together and fed back to the landscape level. This process involves several iterative steps to translate, synthesize and distil all of the information into a high-level summary roadmap (i.e., Strategic Technology Roadmap for Tech Lab), where shows an appropriate visualization of three overarching layers explaining “Why”, “What”, and “How” for all topics against an explicit timeline (“When”). In addition, a linkage grid is used to depict the relationships between three layers, as well as to capture push vs pull linkages for the set of topic-level opportunities. Finally, after the determination of key topics and the development of Strategic Technology Roadmap for Tech Lab, the STRM is engaged with the Demand Management, facilitating a more comprehensive exploration of product-level concepts (i.e., the project level) that are aligned with these key topics. At this point, the foresight and strategic planning process comes to an end and transitions seamlessly to the existing innovation process (i.e., the Damand Management process) that begins with product-level idea gathering (i.e., the Long List development).

It is important to note that the entire STRM process is designed to last eight months, with an interval of one to two months between activities. This purposeful spacing allows participants sufficient time to conduct research, complete their assignments, so that to contribute more effectively to the workshop. Moreover, in consideration of the extensive efforts of the internal workforce, it is determined that the STRM process will synchronize with the corporate strategy process by executing the entire procedure every three years, and reviewing and revising the roadmap every year. Thus, the results of STRM are also used as a valuable input that contributes to the definition of corporate strategy.

5.2.2 Implementing the STRM process

According to the plan, the new STRM process was successfully implemented at Tech Lab from October 2022 to May 2023. It involved a total of 65 participants, comprising managers, technical experts, and marketing experts of Tech Lab, who were either partially or fully engaged in the process. Table 5.1 provides an overview of the timeline, a summary of the activities, and the deliverables for each individual phase. A detailed process review of each step is explained in Appendix B. In the end, the foresight workshops yielded a set of 11 long-term trends and drivers, along with a corresponding list of 12 future topics and a set of topic roadmaps for both future topics and current strategy topics. All of the future topics exceeded the scope of the current strategic framework. At the conclusion of the process, both future and current strategy topics were included on the final roadmap and planned at the business level.

Table 5.1: Overview of the new round of STRM exercises in Tech Lab

Time	Steps	Summary of activities	Deliverables
Oct 2022	Sharing current strategy (“Sharing Day” workshop)	Range Managers share the current strategy, as well as new topics discovered by each range throughout the past year	Current strategies on the strategic landscape roadmap
Nov 2022	Strategic foresight workshop – Trends and drivers	Discuss new trends and drivers that would impact Tech Lab´s strategy in a long term	Top 11 trends and drivers

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Table 5.1 (*continued*)

Time	Steps	Summary of activities	Deliverables
Jan 2023	Strategic foresight workshop – Value propositions	Discuss future value proposition ideas to address top trends and drivers, and determine a set of key future topics	Short list of 12 future topics
Mar – Apr 2023	Topic roadmapping	Analyze the prioritized topics in detail and roadmap the path for topic development; Incorporate the current range strategies into topic roadmaps	Topic roadmaps of both future topics and current strategy topics; business cases; technology review
May 2023	Synthesis roadmapping workshop	Engage all of the key topics and develop the Strategic Technology Roadmap for Tech Lab	Strategic Technology Roadmap for Tech Lab

5.2.3 Evaluating the results

An analysis of the results derived from implementing the new STRM process in Tech Lab was conducted between June and December 2023. The analysis focused on two parts of the results: 1) the value contributions achieved through the implementation of STRM, that is, the outcomes linked to strategy, organization, and innovation performance; and 2) the challenges encountered during the STRM process and possible improvements for the future.

5.2.3.1 Value contributions of STRM

Based on the initial objectives that we established for the implementation of STRM, it is crucial to know whether all of them have been accomplished, as well as to identify any additional value contributions that have been made. The initial phase involved the core team conducting an analysis of the qualitative outcomes. This was done in light of the feedback and comments received throughout and after the workshops, as well as in other organizational events and meetings where the STRM was discussed. In addition, informal conversations with the participants, the top management team, and other colleagues were also considered in the assessment. Apart from that, we conducted a comparative analysis of these qualitative data with existing literature in order to classify them in a more precise way.

In order to analyze the quantitative results, we waited until the completion of the subsequent Demand Management activity to check how many product ideas were proposed based on the future topics generated from the process. This is to assess the overall integration level of STRM with the existing organizational process, as well as its efficacy in terms of innovation performance. Finally, both qualitative and quantitative outcomes were examined and organized into three categories: strategy-related outcomes, organization-related outcomes, and performance-related outcomes. Table 5.2 summarizes the key outcomes or value contributions of implementing the STRM in Tech Lab.

Table 5.2: Key outcomes of implementing STRM in Tech Lab

Outcomes		**Description**
A. Strategy-related	I. Strategic alignment	- STRM allows different ranges to present and share their range strategies in front of other teams by using the same roadmap format, thereby facilitating the alignment of organizational members' understanding of strategies. - Ensures the Tech Lab strategy in line with the corporate strategy.
	II. Strategic flexibility	- STRM provides a structured approach to discuss and identify disruptive areas that may have a significant impact on the business in a regular basis. - Increases the organization's capacity to respond and adapt quickly to changes.
	III. Strategic decision-making	- The final roadmap facilitates disseminate the strategy inside the company and directs managerial decisions to conform to the strategy.
B. Organization-related	I. Communication	- STRM allows extensive collaboration between cross-functional teams. - Provides a platform for organizational learning.
	II. Organizational change	- Discussion on future changes breaks dominant mindsets and promotes organizational change.
	III. Consensus-building	- STRM allows the lower-level organizational members to collaborate in addressing unique strategy challenges, deliberating on development plans, and reaching consensus before taking actions.

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Table 5.2 (*continued*)

Outcomes		**Description**
C. Performance-related	I. Innovation outcomes	- A total of 12 future topics were detected from the foresight workshop. - The process is integrated with existing operating model and promote concrete innovation ideas in the subsequent Demand Management process.

Strategy-related outcomes. The STRM, being a process that integrates innovation foresight and strategic planning, has inevitably produced the 'traditional' results predicted by other studies based on the general application of foresight tools (Battistella and De Toni, 2011; Marinkovíc et al., 2022). This involves a wide range of strategic management improvements including *strategic alignment*, *strategic flexibility* and *strategic decision-making*. First, the STRM facilitates the sharing and discussing of current range strategies among different ranges by gathering various team members into a workshop and using the same roadmap format. This allows for the alignment and presentation of diverse range strategies in a consistent manner, hence improving the comprehension of strategies among team members. In addition, the STRM workshops serve the dual purpose of ensuring the alignment between the business-level Tech Lab strategy and the corporate-level Repsol strategy and potentially influencing the latter’s long-term development by the provision of inputs on foresight.

Furthermore, identifying foresight topics throughout the STRM process contributes to the systematic development of long-term strategies in Tech Lab. It ensures the formulation of the long-term strategy is done systematically, but not sporadically. Overall, STRM provides a structured approach to identifying disruptive areas that may have a significant impact on the business, as well as to regularly planning for resources and capability development, thereby enhancing the organization's capacity to respond and adapt quickly to changes induced externally. In addition, the roadmap's visualization feature, which consists of creating several potential routes from the current to the vision point on the roadmap framework, made participants' long-term planning efforts easier. A clear presentation of the strategic content on the final roadmap also facilitates disseminate the information inside the company and directs managerial decisions to conform to the strategy.

Organization-related outcomes. Soft factors caused by the process, such as *communication*, *organizational change*, and *consensus-building*, are represented by outcomes relating to the organization (Marinkovíc et al., 2022). First, the STRM process improves communication inside the organization and facilitates organizational learning. It involves extensive collaboration between cross-functional teams working on various tasks, from the "Sharing Day" workshop which helps participants understand the work their colleagues are working on, to the foresight and topic roadmapping workshops that require participation in sharing experiences, exchanging ideas and values from diverse perspectives, and encouraging creative thinking among participants. During the process, it enhances awareness of organizational members for potential disruptions and the need for change. The STRM provides a platform for organizational members to discuss about future changes, which helps everyone consider where they are now, and eventually break dominant mindsets and promote organizational change. Ultimately, it is not only the responsibility of middle managers and the top management team to develop strategies; lower-level organizational members must also collaborate to address unique strategy challenges, deliberate on development plans, and reach consensus before taking actions.

Performance-related outcomes. Performance-related outcomes constitute the quantitative assessment of the *innovation performance* by implementing the STRM. This includes the output of STRM exercise and its impact on the subsequent innovation activity. Although one part of STRM emphasizes the importance of strategic alignment and engagement in order to ensure all key strategy topics are presented on the final roadmap, the foresight activity it brings has completed the front-end innovation process in Tech Lab and is regarded as a unique and significant contribution by the STRM. As a direct result of the foresight workshops, a total of 12 future topics were identified and considered crucial for the long-term strategy development in Tech Lab. A topic roadmap is also established for each of them, outlining the specific short-, mid- and long-term development plans that guide their future research and development activities.

The second part deals with the outcomes of Demand Management. We analyzed, upon the completion of the Demand Management process of the year, how many product ideas from these future topics were suggested in the Long List and the Short List. Given that the Long List serves as the first step in the Demand Management, wherein innovative ideas were previously derived from gathering ideas and demands from internal business units, the implementation of STRM allows more long-term innovative ideas to be originated directly from the future topics. The Short List further determines partial of the products that are deemed suitable for development after applying business constraints. To assess the efficacy of the STRM process and its overall level of integration within the organization, it is valuable to examine the number of innovative product ideas that originate from foresight topics using both the Long and Short Lists. At the end, among the 12 future topics, a total of 51 product ideas were proposed in the Long List, covering 10 future topics; 21 products covering all of the 10 future topics were further advanced to the Short List, and were determined to be developed in 2024. The results are summarized in Table 5.3.

Table 5.3: Linkages between products and future topics in the Demand Management

Demand Management	Innovative product ideas	Number of future topics covered (among 12 future topics)
Long List	51	10
Short List	21	10

5.2.3.2 Challenges during the process

Despite these achievements, we experienced a number of challenges throughout the process. These issues were brought up at one management meeting in Tech Lab, and several actions were proposed by the core team to further enhance the process in the next cycle. This describes the key learnings from the second-round action research.

One of the biggest challenges we encountered was fostering active participation and enhancing individuals' commitment throughout the process. For example, some of the delegates failed to complete and submit their pre-work on time, resulting in challenges for the core team in reviewing the assignments and preparing for the initial assessment prior to the workshop. A few delegates who made the commitment to the workshop but failed to attend, which could have potentially jeopardized the process, specifically the activity that required delegates to collaborate with various designated roles in order to accomplish a task as a team. Some other delegates also neglected to conduct the individual assessment during the post-workshop activity of prioritizing the topics, ideas, etc. This prevented the final results from accurately reflecting the opinions of all key stakeholders. To improve this part, extensive and effective communication between the core team, participants, and management is crucial. In the future STRM process, it will be vital for the core team, at the start of each round, to explain explicitly the aspects including the need, methodology, deliverables, and objectives of STRM to all teams, to clarify the various roles of individuals in the process and their expected contributions, as well as to provide a comprehensive documentation to everyone.

Furthermore, with regard to enhancing innovation performance through the implementation of STRM, while we have accomplished 83.3% of future topics (10 out of 12) proposed with tangible product ideas in the Long List, this rate did not reach 100%. If it has been established that every future topic is crucial for our long-term development, then during the ideation process, we should propose as many concepts that encompass all topics as possible. Therefore, it would be beneficial, in the future process, to assign a Topic Champion to each topic once the STRM is completed, who will help promote the topic within Tech Lab, stimulate more product ideas in the Long List, and maintain a comprehensive and cohesive understanding of the progress of all future topic activities within Tech Lab.

Chapter 6
Discussion

At this point, this action research, which includes two research cycles, has captured and reported on the process journey of how roadmapping as a foresight and strategic planning tool was initiated, developed, and integrated into the existing process of Tech Lab and resulted in favorable outcomes in improving the organization's strategic responsiveness and innovation capacity. In the existing literature, there has been ongoing discussion regarding the critical success factors that contribute to the successful organizational roadmapping process based on either survey (e.g., Phaal et al., 2001b, Lee et al., 2011, Münch et al., 2019), or company cases (e.g., Gerdsri et al., 2010; Kerr et al., 2019; Hirose et al., 2001, 2002, 2003; Daim et al., 2018). However, most of these studies examine these factors by focusing on the effectiveness of the roadmapping process itself, such as the workshop's usability, functionality, and utility, rather than its impact on business-related performances. Furthermore, given the various application settings of roadmapping (e.g., product planning, corporate foresight and strategic planning, technology planning), it is observed that the factors contributing to success tend to vary. For these reasons, it is necessary to do a thorough analysis to determine the critical success factors that are crucial for initiating, developing, and sustaining the roadmapping process in the context of Tech Lab. This will allow other companies to gain a better understanding of how to develop an efficient roadmapping process in the same context, achieve positive results, so as to keep it ‘alive’. Therefore, this Chapter will first discuss a series of success factors that the Tech Lab's case has identified as essential for establishing and sustaining an efficient roadmapping process within a business, as well as identify and highlight the distinctions between these factors and those identified in the previous research. After that, a distinctive role of the STRM in tackling grand challenges will be discussed. We found that the implementation of STRM in Tech Lab contributes to several key issues that are relevant for addressing grand challenges, which include facilitating open discussion, reflection and refinement of future visions, aligning business strategies with a balanced perspective, and cultivating a deep sense of purpose among stakeholders. In the last part of this Chapter, an analysis is conducted to explain the limitations of the study and outline potential avenues for future research.

6.1 Success factors

According to Gerdsri et al. (2010), there are three key underlying factors that contributes to the successful implementation and integration of organizational roadmapping, namely, “people”, “processes”, and “data”. This research builds upon this study by analyzing the components within these three categories to investigate the characteristics that contribute to the success of STRM process, followed by comparing these factors with the feedback and comments received inside the Tech Lab. We found that, in addition to all three criteria being crucial, the factor of "organizational culture" is also vital in initiating and sustaining the roadmapping process. In this section, an in-depth review of the main findings from Tech Lab's case research is provided. Key success factors within the four categories of “people”, “processes”, “data”, and “organizational culture” are examined and discussed in detail. A comparison with prior research is also included to highlight the essential components in sustaining an efficient roadmapping process inside an organization. Table 6.1 provides a summary of all the success factors based on the analysis.

Table 6.1: An analysis of success factors for developing and sustaining roadampping process in Tech Lab

Success factors		**Key insights**
A. People	I. Selection of right stakeholders	- Cross-functional participating members in the roadmapping workshops. - The personnel configuration should be tailored to the specific goals of each workshop/activity.
	II. Creation of a dedicated core team	- Motivate participants by acknowledging their efforts. - Actively communicate to raise awareness of roadmapping at all stages. - Ensure adequate training and advance their knowledge in roadmapping.
	III. Constant support from top management	- Get support and sponsorship from high-ranking officials from early on. - Have them establish priorities for the exercise to legitimize the process, and drive the momentum of the working teams.
B. Processes	I. Testing with a reference process	- Test with a reference process and collaborate for the first time with an experienced consultancy would enable a better customized approach to suit the organization.
	II. Customization of the reference process	- Adapt the reference process to the organizational structure, business cycles, and working culture.

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Table 6.1 (*continued*)

Success factors		**Key insights**
B. Processes (*continued*)	III. Incorporating the process into strategy development	- Start the process with a clear picture of current strategy. - Customizing and formalizing the process to be integrated with the strategy development will validate the results to be implemented.
C. Data	I. High-quality data inputs	- Incorporate diverse perspectives from both internal and external sources. - Assign pre-work to participants and allow sufficient time to complete. - Develop an efficient process of external data collection, processing, and sharing.
	II. Post-process data accessibility	- Grant access to the resultant roadmaps and other pertinent information to the entire organization after the completion of process.
D. Organizational culture	I. Openness of culture	- An open culture facilitates the establishment of roadmapping, and collaboration among participation members.
	II. Transparency	- Transparency promotes the inclusion of lower-level employees and decision-makers to collaborate on the development of the organization's strategy plan.
	III. Managerial mindset	- A forward-thinking and willing-to-change mindset speeds up the formalization of the process and execution of the strategies.

6.1.1 People

The process of implementing a roadmap is complex and requires the participation of a diverse group of stakeholders (Gerdsri et al., 2010; Hirose et al., 2020). Prior research indicates that the careful *selection of right stakeholders* to participate in the roadmapping workshop is crucial (e.g., Phaal et al., 2001b; Daim et al., 2018; Münch et al., 2019; Hirose et al., 2022). In particular, these studies highlight the need of clearly defining the roles and responsibilities of the people involved (e.g., Daim et al., 2018), as well as ensuring cross-functional staff participating in the same workshop (e.g., Phaal et al., 2001b). While we acknowledge the importance of these factors, we found that the careful selection of appropriate stakeholders to engage in different activities has significantly contributed to the positive outcome of the process in Tech Lab. To be specific, within the STRM, the individuals who participated in the foresight workshop are distinct from those who take part in the topic roadmapping exercise. This is because, the foresight workshop, which concentrates on landscape development, necessitates a group of people with a comprehensive understanding of strategy and the authority to make decisions. On the other hand, topic roadmapping requires real subject matter experts (e.g., technical and market experts) to delve into selected landmarks in order to identify opportunities with a greater level of detail. This information can, then, be used to inform higher-level discussions and integrate it into the overall landscape. We found that, when various activities are interconnected by a single high-level roadmap, it enhances the understanding and communication of each other's work. Consequently, tailoring the personnel configuration for each activity can ensure the production of high-quality outputs while minimizing the risk for ineffective coordination and communication between different activities.

In line with previous research, the case of Tech Lab has found that *the creation of a dedicated core team* for the roadmapping process is another factor crucial for its success. Inside the core team, it is essential to have members who have received adequate roadmapping training (Hirose et al., 2021, 2022, 2023). In the initiation stage, the core team is responsible for raising the awareness of why roadmapping is needed, discussing the detail concept and the roll-out plan, communictating the vision for buy-in and support from key stakeholders, and preparing all participants to be ready to implement the roadmapping process (Gerdsri et al., 2010). In the development stage, it is important for the core team to perform effective facilitation inside the workshops (Phaal et al., 2001b), and remove any barriers that block participants from carrying out their roadmapping activities (Gerdsri et al., 2010). In the integration stage, the core team is also responsible for organizing actions to regularly maintain and update the roadmap inside the company. Apart from these, Tech Lab's case has revealed that in order to ensure a good result of the roadmapping activities, it is critical to motivate participants by recognizing the value of their efforts, as well as to consistently raise awareness of roadmapping at all stages to ensure their engagement (which has been identified as a significant challenge that requires improvement in future exercises). Furthermore, in order to enhance their proficiency in roadmapping, it is imperative that the core team stay updated on the newest advancements in roadmapping. As the team gains more experience, its trust among participants increases, leading to more confidence and the ability to create high-quality results.

In addition, receiving *constant support from top management* is proved to be key. This is due to the fact that roadmapping entails change management (Gerdsri et al., 2010), and the implementation of roadmapping foresight activity is likely to be supplementary to the daily tasks of organizational members. Without the constant support from top management, it can be challenging to progress due to organizational inertia. In the case of Tech Lab, the roadmapping initiative gained acceptance and sponsorship from top management at the outset. They arranged a company-wide meeting to kick-off the project, explaining its importance to the company. During the development and integration stage, top management also set up special meetings along with managers to review the process after the key milestones were achieved.

Strong enthusiasm and support from top management helps to maintain the momentum and energy from all participants; having them establish priorities for the exercise would further legitimize the process and facilitate its progression.

6.1.2 Processes

Almost all of the prior studies have shown the importance of customizing the roadmapping process to fit with the organizational setting and working culture (e.g., Lee et al., 2011; Daim et al., 2018; Münch et al., 2019; Hirose et al., 2020). However, the Tech Lab's experience has illustrated the significance of the pre-customization procedures, that is, establishing a clear understanding of the intended purpose of roadmapping implementation, *testing with a reference process* (the S-Plan process in our case), and collaborating with an experienced consultancy for the first time. This finding was barely mentioned in the previous research, with the exception of the roadmapping case conducted at LEGO Group (Kerr et al., 2019). In the case of Tech Lab, conducting a trial run on the reference process helped to boost the participants' confidence in the process because they knew that it had been extensively and rigorously tested in the industry. And, through the investment of a single workshop, the organization gained an understanding of the potential outcomes and allowed for early buy-in to the roadmapping tool. Working with an experienced consultancy also helped the organization grasp the fundamental principles of the standard methodology more quickly, thereby enabling a better customized approach to suit the organizational structure, business cycles, and working culture.

Then, obviously, *the customization of the reference process after the trial phase* is also crucial. This is due to the fact that the reference process strives to establish a 'fast-start' approach that adopts a rapid prototype philosophy and embodies the ethos of "iterating quickly as a learning process" (Phaal et al., 2012), it offers a baseline for customization (Kerr et al., 2019), but can only be "used as a starting point from which the method is adapted as required" (Phaal et al., 2012). While it has been demonstrated in other organizational cases that the one-day workshop of the S-Plan baseline process can provide a sufficient quality of input-versus-output against an acceptable level of commitment from key stakeholders (Phaal et al., 2004c), one problem discovered during the first trial of Tech Lab was that insufficient time allocated to the discussion on the trends and driver layer, in particular, would result in a limited understanding as to the significance and implications of the STEEPLE factors on the propose of opportunities (i.e., future topics). To address this, we divided the strategic landscape workshop into two parts (i.e., Step 2 and 3 in Figure 5.5) and allowed sufficient time for reflection between them. The final STRM process is, thus, the result of the customization of the S-Plan process. By taking into account the organizational processes and working culture in Tech Lab, it splits the different parts of the S-Plan process and includes an additional procedure at the beginning (i.e., the "Sharing Day" workshop), and is then spread out over a period of eight months to achieve an optimal result.

Furthermore, in line with other research, our case has also demonstrated the importance of sustaining the foresight or roadmapping activity to be *incorporated into strategy development process* in the organization (e.g., Farrington et al., 2012; Daim et al., 2018; Hirose et al., 2022). We believe that this is the primary reason for considering a regular implementation of STRM in Tech Lab, since the outcomes of this process determine the formulation of strategies that compel organizational members to adhere to the established plans. Our case has also emphasized the importance of starting the process with a clear picture of current strategy. We believe that an inadequate structure (e.g., a single one-off workshop event) and a lack of integration of the outcomes of the foresight exercise into the decision-making process can lead to discontent among organizational members and cast doubt on the legitimacy of the exercise results.

6.1.3 Data

It has been acknowledged that the success of a roadmap is linked to the quality of knowledge captured (e.g., Phaal et al., 2001b; Gerdsri et al., 2010; Daim et al., 2018).

Nevertheless, the high-quality content displayed on the final roadmap is a result of using *high-quality data inputs* in the process, and obtaining such high-quality data inputs has become a major concern for Tech Lab. In particular, incorporating both internal and external knowledge was designated as one of the objectives of STRM in order to expand the scope of foresight areas, facilitate the recognition of numerous significant future factors, and promote a holistic approach to decision-making. To enhance the integrity of internal data, participants were given sufficient time to complete the required pre-work, allowing them to thoughtfully develop their perspectives. The assignment of pre-work significantly increased the breadth and depth of inputs and also allowed the facilitators to filter and iterate the inputs and views, ensuring the inclusion of high-quality internal inputs. In order to improve the quality of external data, developing an efficient process of external data collection, processing, and sharing is essential. By utilizing a wide range of knowledge sources (e.g., conducting interviews or surveys with academic and industrial experts from various fields; gaining access to credible marketing and technology intelligence reports, patents, and paper; collaborating with consulting firms to obtain the most recent development information), establishing an efficient information processing capability (e.g., utilizing data mining tools), and implementing an efficient internal knowledge transfer system, we can ensure that the external knowledge included in the process is sufficient and of high quality. While it is not an easy task and an ongoing research topic in the Tech Lab, our case has shown that ensuring the high-quality outputs derived from high-quality data inputs into the process will strengthen the roadmap's credibility and generate confidence in the organizational members to execute strategic plans, thereby sustaining the process.

Additionally, *post-process data accessibility* throughout the entire organization has found to be critical for the process longevity. This is because roadmapping workshops are not the end of the strategy planning and foresight activity, but just the starting point for a much wider engagement with stakeholders (Kerr et al., 2019). The resultant roadmaps can be used as a visual validation to communicate with relevant stakeholders (Hirose et al., 2023), serving as a forum for on-going dialogue across functional areas of the organization. Therefore, both the participants and the rest of the company need be granted access to the final roadmaps. This will guarantee improved understanding of strategic plans and streamline the implementation and integration of following innovation efforts inside the organization. Furthermore, allowing the whole company to scrutinize and discuss the content of the roadmap would ensure the visibility of roadmaps and resulting in their improvement.

6.1.4 Organizational culture

Transition to a roadmap-based planning process is a major cultural change that requires individuals to adapt to new processes and procedures (Cosner et al., 2007). While Gerdsri et al. (2010) doesn't consider "organizational culture" as one of the most important categories that contribute to the success of the roadmapping process, some other studies acknowledge its contribution during the development stage. For instance, Daim et al. (2018) highlight the importance of a supportive culture that fosters collaboration across departments. Similarly, Münch et al. (2019) emphasize the value of openness, respect, and honesty in creating a positive working environment for the roadmapping process. Inside the Tech Lab, factors related to organizational culture have been found to play a particular role in not only the effective implementation, but also the initiation and maintenance of STRM. These include *an open culture*, *transparency*, and *managerial mindset*.

Resistance to change is expected to be present at all stages of roadmapping (Gerdsri et al., 2010). At the initiation stage, the level of resistance rises when key stakeholders are skeptical about the value of roadmapping and require additional information to understand its scope and direction. As the implementation starts, resistance may easily increase when participants hold opposing views. During the integration stage, the level of resistance could rise again when the new roadmapping process are established and more people are involved, in which people are forced to change and adopt new ways of working. In Tech Lab, a culture of openness has long been fostered by providing employees enough freedom in proposing innovation initiates, actively pursuing sustainable solutions through open innovation and establishing partnerships with others. This culture serves as a prerequisite that promotes a sense of ease among organizational members in starting a new initiative, collaborating with each other and integrating varied sources of knowledge to collectively explore future prospects. An open culture also promotes transparency throughout the process, allowing the inclusion of lower-level employees and decision-makers to collaborate on the development of the organization's strategy plan. A forward-thinking and willing-to-change managerial mindset of the management team speeds up the formalization and integration of roadmapping process into the organizational processes and actively implements the strategies derived from the process.

6.2 Addressing grand challenges

Among all of the comments gathered from the participants, one captured our attention. Some of our participants believe that the adoption of STRM in Tech Lab is going to make an important contribution towards tackling the grand challenges of the society (George et al., 2016; Ferraro et al., 2015). At the regional or national level, foresight has been recognized as a powerful tool for addressing grand challenges (Cagnin et al., 2015). By facilitating community participation in decision-making processes concerning their future, it serves as an effective means for establishing political priorities on issues that affect a wide range of societal stakeholders. At the organizational level, organizations are also motivated to implement practices and formulate strategies to tackle components and milestones in the pursuit of grand challenges (George et al., 2016).

Repsol, which was originally an oil and gas company, has committed the society in addressing net zero targets, navigating the transition towards a more sustainable and low-carbon energy business. However, the energy transition encompasses regulatory, market, and technological risks associated with the deployment of renewable energy solutions. Balancing short-term financial performance with long-term sustainability goals poses a challenge to the company but is particularly important during the transition period to ensure a long-term survival.

The implementation of STRM in Tech Lab contributes to several key issues that are relevant for addressing grand challenges. First, grand challenges are typically the result of substantial changes or transformations in various aspects of the world we live in (e.g., the STEEPLE landscape). The corporate foresight activity within the STRM empowers Tech Lab to anticipate these changes early on. It provides a platform that enables a joint discussion on the shared goals and vision among a group of participating members from different groups and functions, and the combination of relevant information on future trends based on both evidence and collective intelligence, enabling them to proactively respond to the changes rather than reactively adapting to them. With the help of roadmapping, decision-makers can use the information gathered through foresight to formulate achievable but inspiring goals, align their business strategies with these trends, and make informed decisions that position them to address these challenges. The STRM fosters a culture of adaptability and resilience within the company, enabling it to become more agile and better prepared to changes, which is essential when dealing with grand challenges that may evolve over time (George et al., 2016).

Furthermore, grand challenges, due to its inherent uncertainty and complexity, require coordination from multiple and diverse stakeholders, including governments, NGOs, and other companies. The STRM allows the company to identify potential partners to address these challenges through collaborative effort. Finally, as solutions to grand challenges often necessitate shifts in both individual and societal behaviors (George et al., 2016), the adoption of STRM has effectively underscored a profound sense of purpose among employees. It highlights the potent role of sustainability issues as compelling drivers, forming a powerful force that unites people in the collaborative pursuit of solutions to complex and significant challenges.

Overall, the STRM proposes a solution for harmonizing the “triple bottom line” (Elkington, 2013) of economic prosperity, environmental protection, and social equity inside Tech Lab. By incorporating sustainability thinking into strategy planning, it acts as the initial stage of business activity and promotes the achievement of future sustainable commitments.

6.3 Limitations and future research

The limitations and future research are addressed in two parts. The first part is related to the foresight methodology utilized in the action research, and the second is related to the approach we took when examining the process's outcomes or value contributions.

6.3.1 Foresight methodology

This research focuses on conducting foresight activities based on roadmapping by integrating it with traditional foresight methodologies that combine expert opinions and trend analysis. However, other widely used foresight tools can also be utilized to complement roadmapping which could potentially yield more robust foresight outcomes. Scenario planning, Delphi technique, and AI are a few examples.

Scenario planning is considered as the most prominent and one of the most powerful techniques in corporate foresight (Rohrbeck et al., 2015). By integrating the external perspective (external scenarios) with the internal perspective of resource and strategic options (internal scenarios), this tool facilitates the pursuit of an optimal solution in uncertain environments (Fink et al., 2005; Rohrbeck and Schwarz, 2013). Our literature review in TRM case studies has revealed that scenario-based roadmapping development is a growing trend in roadmapping research to study emerging markets and technologies, identify weak signals, and formulate strategies and innovation policies in uncertain environments. However, since the current body of case studies primarily investigates its application at the macro-level (i.e., at the national and industrial levels), leaving the micro-level (i.e., organizational level) application for corporate planning at the exploratory stage of research. The current literature has also proposed multiple approaches of integrating scenarios into roadmaps (e.g., qualitative approach by Hussain et al. (2017); quantitative approach by Lee et al. (2016), Son et al. (2019); a mixed approach by Hansen et al. (2016), Lee et al. (2015)). While the investigation of the scenario-based roadmapping approach was not the primary focus of this two-cycle action research, we intend to delve deeper into this topic and establish a desired approach for Tech Lab in the future exercise.

In addition, the Delphi technique has proven to be powerful in consolidating expert opinions in an informed way (Kahn and Wiener, 1967). Surveys using the Delphi technique could be conducted to include external insights on emerging trends, which includes a process that guarantees the arguments and opinions of all participants being considered, rather than just those of the average or most vocal experts (Rohrbeck et al., 2015). Moreover, AI is currently being implemented more often in the field of foresight to assist organizations in reducing the time needed to transform signals into insights and action, thereby facilitating the transition to real-time decision-making (Gordon et al., 2020). Future research at Tech Lab can concentrate on testing these methodologies, implementing them along with roadmapping. This will determine if the utilization of these tools assists in the development of a more comprehensive vision of the future, enhances the interpretation of change, and supports the sustainability of the process.

6.3.2 Evaluation of outcomes

In this action research, the organizational impact of STRM were assessed primarily by analyzing the feedback and subsequent actions taken after the adoption of the process. However, the current literature suggests that the value contribution of the roadmapping process can also be quantified by examining process-related measures of each workshop (Boe-Lillegraven and Monterde, 2015; Farrukh and Holgado, 2020), for example, by checking the usability (i.e., whether the workshop was easy to implement for both facilitator and participants), functionality (i.e., whether the workshop does what it was designed to do), and usefulness (i.e., whether the workshop activities have an impact on organizational decisions) immediately after the workshops using questionnaires. This will yield more quantitative results that capture the overall perceptions of participants in related to each workshop, which will be helpful for improving future events. Apart from that, interviews could also be conducted to carefully assess the differences in comments and suggestions across participants of different levels and roles.

Furthermore, it is important to note that while this longitudinal action research has successfully investigated the business-related innovation performance by analyzing the quantity of foresight topics integrated into business strategy and the new product ideas associated with these topics in the subsequent organizational process, the future profitability of commercializing these product ideas and the profitability of foresight topics cannot be estimated at this time due to the long-term orientation of the foresight activity. It will be necessary to monitor the research activities associated with these topics in the coming years in order to accurately assess the impact this process will have on business performance.

Chapter 7
Conclusions

Within the field of innovation and technology management, roadmapping has proven to be a powerful tool for organizations to practice foresight activities, enhance the validity and robustness of strategies by bringing together divergent perspectives on technology analysis and market projections, and translate strategies into concrete business plans. However, although roadmapping is both an established and proven tool, there is a dearth of rich organizational accounts on how to initiate, develop and sustain its deployment in order to obtain tangible business outcomes.

As an industrial PhD candidate conducting research in a real corporate environment, my doctoral research focuses on utilizing cutting-edge knowledge in the field of management to assist the organization in solving real management challenges, and simultaneously, integrating the practical experience and knowledge acquired to enrich the academic theory. During the course of my PhD studies, I am delighted to discover the methodology of roadmapping and to conduct a comprehensive review of existing literature in this topic first. Following that, I utilized the findings gained from my research to carry out an action research project focused on developing and sustaining a roadmapping-based foresight process (i.e., the STRM process) at Tech Lab for over 30 months.

The two research cycles of the action research conducted in Tech Lab presents its experience of initiating roadmapping by trialing a reference process, and then, based on feedback and lessons learned, adapting it to create its own roadmapping process that is integrated into the ongoing organizational process. The action research entails action and reflection cycles and iterative learning through incremental improvements.

The resulting STRM process has effectively addressed the absence of a systematic approach inside Tech Lab for analyzing the environment, detecting weak signals, and shaping long-term strategy that enables the company to explore new markets, products, and services. It integrates corporate foresight and strategic planning process with a structured approach to define the short-, mid- and long-term roadmap of activities in Tech Lab, operating as a precursor to Demand Management in order to supplement it in developing a comprehensive front-end innovation process. After 30 months of research, the STRM has successfully merged with the existing management process, leading to positive innovation outcomes and other outcomes related to strategy and organization, including enhanced strategic alignment, flexibility, decision-making, facilitated organizational change, improved communication and collaboration between teams, and consensus-building among members of the organization. “People” (e.g., selection of right stakeholders, creation of a dedicated core team, the constant support from top management), “processes” (e.g., testing with a reference process, customization of the reference process, incorporating the process into strategy development), “data” (e.g., high-quality data inputs, post-process data accessibility) and “organizational culture” (e.g., openness of culture, transparency, managerial mindset) are factors that contribute to the successful initiation, development and maintenance of STRM. Future improvements of the STRM in Tech Lab will prioritize enhancing participant engagement, designating Topic Champions to better interact with Demand Management, improving process of external data collection, processing, and sharing, and refining foresight techniques by researching and experimenting with alternative foresight tools.

7.1 Contributions

My doctoral research makes several practical and theoretical contributions to the field of innovation management and roadmapping. First of all, my research provides a comprehensive overview of the existing literature on applied roadmapping case studies. From a practical perspective, it helps *industrial practitioners* who want to apply roadmapping find the most recent findings and relevant applications within the existing body of literature. Moreover, despite its prevalence in industry for over six decades, roadmapping as a strategic and innovation planning methodology and practice is seldom covered in mainstream business schools, teaching programs, and textbooks. Therefore, in addition to industrial professionals, my research endeavors to raise awareness of the roadmapping methodology to *a broader audience of innovation practitioners in scientific environments*, such as universities and public research centers, where the challenge of "knowledge transfer" hinders the conversion of scientific knowledge into market solutions. Roadmapping may effectively address this issue through the implementation of a workshop-based methodology (which entails the active participation of various domain experts in the iterative development of roadmaps) and by delivering a dynamic systems framework (which concurrently takes into account the "technology-push" and "market-pull" aspects to furnish a comprehensive framework for innovation pathways and system evolution).

Furthermore, my doctoral research delivers an in-depth longitudinal action research study that offers valuable insights to *industrial practitioners* who wish to enhance strategic planning and foresight capabilities within their organizations. In particular, it presents an organizational roadmapping-based foresight methodology and provides valuable guidance on how an organization can efficiently design, develop, and integrate that methodology into the organization. The lessons learned and the key success factors indicated throughout the process can be utilized to help other companies avoid the same dilemma and cultivate the skills required for effective roadmapping. By offering empirical evidence and indicating various kinds of value contributions of the implementation, it enhances confidence and improves the likelihood of success for other companies looking to adopt a similar roadmapping approach.

From an academic stance, the action research conducted in Tech Lab contributes to *the existing body of roadmapping literature* by expanding the scope of investigation to include the integration stage. Through an in-depth longitudinal action research, the identification of organizational performance enriches the literature with providing the true value impacts of applying roadmapping, while also offering compelling evidence for the importance of maintaining a follow-up stage inside a company. Analyzing success factors and comparing them with prior literature provide a chance to enhance comprehension of the criteria for an effective organizational roadmapping process across all stages. Additionally, this action research emphasizes the benefits of using action research method to advance the application of management tools like roadmapping. This involves improving knowledge of the application in a live company case that is based on tangible feedback and subsequent iterations for continued improvements. Lastly, this research highlights key issues in roadmapping-based foresight activity that are relevant for addressing grand challenges in an organizational context, providing insights for *management scholars* to explore and enhance management practices in order to tackle these challenges at this critical moment.

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Appendices

Appendix A - Literature summary of 79 case studies in TRM

Authors	Research area	Level	Research method	Study on
Arianto and Surendro (2017)	Strategic planning	Organizational	single case; qualitative	An integrated method of combining TRM and Business Model Canvas (BMC) applied in an electronic company in Indonesia
Ateetanan and Shirahada (2016)	Strategic planning	Organizational	single case; qualitative	A service roadmap incorporated with open innovation to plan for assistive technologies for the elderly in an R&D firm of Thailand
Bloem da Silveira Junior et al. (2018)	Technology forecasting	Organizational	single case; mixed	An integrated method of combining TRM with managament techniques, morphological analysis and Delphi applied to an auto firm in Brazil
Cheng et al. (2014)	Technology forecasting	Organizational	single case; mixed	A hybrid roadmapping method (HRMM) applied in an ICT firm in China
Cheng et al. (2016)	Scenario planning	Organizational	single case; mixed	A scenario-based roadmapping (SBRM) applied in a global testing, inspection, and certification company in China
Choomon et al. (2009)	Technology forecasting	Industrial	single case; conceptual	TRM for power line communications
Contretas-Medina et al. (2019)	Strategic planning	Regional	single case; qualitative	TRM for improving indigenous coffee production in Guerrero, Mexico

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Authors	Research area	Level	Research method	Study on
Cowan (2013)	Strategic planning	Regional	single case; mixed	TRM for emerging smart grid development in the Pacific Northwest
Cresto Aleina et al. (2017)	Strategic planning	National/ Institutional	single case; mixed	A System Engineering based method for TRM generation for re-entry space transportation systems at European Space Agency
Daim and Oliver (2008)	Technology planning	Organizational	single case; qualitative	The Energy Efficiency Roadmaps implemented at a federal agency in the US
Daim et al. (2011)	Technology forecasting	Organizational	single case; quantitative	Technology Development Envelope (TDE) as a tool for creating a roadmap of future powertrain systems in a Turkish company
Daim et al. (2018)	Benchmarking	Industrial	single case; conceptual	A technology roadmap benchmark applied in the energy sector in the US
Feng et al. (2020)	Technology forecasting	Industrial	single case; quantitative	A morphology analysis-based technology roadmap incorporating with TRIZ performed in the case of underwear vehicles
Fleury et al. (2006)	Strategic planning	Organizational	multiple cases; qualitative	A technique for customization of the TRM for software companies applied in a university and a software company in Brazil.
Gerdsri and Kocaoglu (2007)	Technology forecasting	Organizational	single case; mixed	Technology Development Envelope (TDE) as a tool for roadmapping of emerging electronic cooling technologies for computer servers in the US

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Authors	**Research area**	**Level**	**Research method**	**Study on**
Gerdsri et al. (2009)	Strategic planning	Organizational	single case; conceptual	Dynamics of TRM implementation with the changing roles of the key players demonstrated by a product manufacturer in the ASEAN region
Gerdsri et al. (2010)	Strategic planning	Organizational	single case; conceptual	Using change management models to support the implementation of TRM for a manufacturer in the ASEAN region
Gershman et al. (2016)	Innovation management/Corporate foresight	Organizational	multiple cases; mixed	Three cases of large Russian state-owned enterprises that implement corporate foresight and TRM for developing innovation strategies
Geum et al. (2011a)	Strategic planning	Organizational	single case; conceptual	A generic structure of product-service integrated roadmap based on a technological interface applied to u-healthcare service in Korea
Geum et al. (2011b)	Strategic planning	Organizational	multiple cases; conceptual	Customization of product-service roadmapping in six business cases (e.g., PC company, healthcare, water treatment, banking, etc.)
Geum et al. (2013)	Open innovation	Organizational	multiple cases; conceptual	A dual technology roadmap for the planning of open innovation applied in three case examples (e.g., automotive, chemical, consumer goods companies)
Geum et al. (2014)	Scenario planning	National	single case; mixed	An integrative approach of combining TRM and system dynamics simulation to support scenario planning in car-sharing business in Korea
Ghazinoory et al. (2017)	Strategic planning	Industrial	single case; qualitative	A learning-based TRM process for developing countries and a case applied in social banking in Iran

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Authors	Research area	Level	Research method	Study on
Gindy et al. (2009)	Project portfolio	Organizational	single case; qualitative	An integrated framework based on STAR (Strategic Technology Alignment Roadmapping) method for guiding investments in R&D projects applied in an aerospace SME companies
Gonzalez-Salazar (2016)	Scenario planning	National	single case; mixed	A modeling framework that combines TRM and scenario analysis to assess the components of the energy-economy-climate system when exploiting bioenergy in Colombia
Haddad and Uriona Maldonado (2017)	Innovation management	Industrial	single case; qualitative	Establishing a non-existing automotive sector in Brazil by means of integrating the functions of innovation systems with the roadmapping process
Hansen et al. (2016)	Scenario planning	Industrial	single case; mixed	A four-step scenario-based TRM method applied in the rail automation market in Germany
Hou et al. (2010)	Technology planning	Organizational	multiple cases; qualitative	Critical factors for the roadmapping introduction phase in Chinese manufacturing companies and a framework with the relationships between these factors
Huang et al. (2014)	Science and technology forecasting	National	single case; mixed	A Science and Technology (S&T) planning model by combining TRM with bibliometric methods to study the Chinese solar cell industry
Hussain et al. (2017)	Scenario planning	Industrial	single case; qualitative	A 'scenario-driven roadmapping' applied in the English National Health Service for Radio Frequency Identification (RFID) technology adoption

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Authors	Research area	Level	Research method	Study on
Ibarra et al. (2013)	Strategic planning	Organizational	single case; mixed	A systematic approach to TRM (SyTRM) applied in a clothing company in Columbia
Ibarra et al. (2014)	Strategic planning	Industrial	single case; mixed	A systematic approach to TRM (SyTRM) applied in developing measurement systems for Oil and Gas sector in Brazil
Igarashi (2015)	Innovation management	Organizational	multiple cases; qualitative	The 'synchronization process' (SP) used in promoting the technologies of R&D and TRM as a tool to discuss its application, with two cases from the mobile phone development in Japan
Jin et al. (2015)	Strategic planning	Organizational	single case; mixed	A technology-driven roadmapping approach applied in the development of solar LED lighting in Korea
Jou and Yuan (2016)	New product development	Organizational	single case; mixed	A method to strengthen the management of the fuzzy front-end in new product development applied in flexible fabric supercapacitor
Kajikawa et al. (2011)	Scenario planning	Industrial	single case; mixed	A social-needs-driven TRM that combines risk analysis and scenario planning applied in the Japanese energy sector.
Kameoka et al. (2003)	Technology foresight	Organizational/Industrial	multiple cases; conceptual	An integrated roadmapping approach that combines forecasting and assessment of emerging technologies applied in Japanese manufacturing companies and industries
Kilkiş (2014)	Strategic planning	Industrial	single case; mixed	An Energy Efficiency Technology Roadmap in Turkey

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Authors	Research area	Level	Research method	Study on
Kim et al. (2016)	New product development	Organizational	single case; qualitative	The design roadmapping process that is driven by the user experiences early in the design process proposed to develop high-tech products in Silicon Valley
Kockan et al. (2010)	Technology forecasting	Organizational	single case; quantitative	Technology Development Envelope (TDE) as a tool for roadmapping future powertrain systems in a Turkish company
Lee et al. (2013)	Strategic planning	National/Regional	single case; mixed	An integrated roadmapping process for services, devices, and technologies capable of implementing a smart city development R&D project in Korea
Lee et al. (2015)	Scenario planning	Organizational	single case; mixed	A systematic approach that provides scenario-based TRM with the ability to assess the impacts of future uncertainties applied in a case of photovoltaic cell technology
Lee et al. (2016)	Scenario planning	Organizational	single case; quantitative	A systematic approach to diagnosing the vulnerability of organizational plans with future uncertainties applied in developing home security systems
Lee and Geum (2017)	Scenario planning	Organizational	single case; mixed	A scenario-based roadmapping using cross-impact analysis (CIA) and the analytical hierarchy process (AHP) as tools applied in u-healthcare services in Korea
Li et al. (2015)	Strategic planning	Industrial	single case; mixed	An integrated approach that combines bibliometrics and a TRM workshop to apply in the dye-sensitized solar cell technology-based industry in China

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Authors	**Research area**	**Level**	**Research method**	**Study on**
Li and Sun (2014)	Technology forecasting	Industrial	single case; quantitative	A technology roadmap for studying wind turbine blade technique by combining bibliometrics and analytical hierarchy process (AHP) method
Li et al. (2016)	Strategic planning	Industrial	single case; mixed	An integrated framework of combining TRM with patent analysis to plan for the emergence of the organic light emitting diode (OLED) industry in China
Lischka and Gemünden (2008)	Strategic planning	Organizational	single case; qualitative	The applicability of the TRM process at a manufacturing unit of Siemens AG in Germany
Liu et al. (2016)	Innovation management	Organizational	single case; mixed	Technology roadmap as a tool for firms to capture innovation opportunities with a case applied in a Chinese manufacturing firm
Loyarte et al. (2014)	Strategic planning	Organizational	single case; mixed	A TRM process with strategic planning techniques applied in an applied research center in Spain
Miao et al. (2020)	Technology forecasting	Industrial	single case; quantitative	A framework that integrates the technology-relationship-technology (TRT) semantic analysis and TRM method for developing elderly smart wear technologies
Milshina and Vishnevskiy (2017)	Strategic planning	National/Regional/Organizational	single case; conceptual	An umbrella roadmap that links together various targeted roadmaps to see a broad picture of an industry with an application in the media industry in Russia
Mitake et al. (2020)	Strategic planning	Regional	single case; mixed	The product-service systems (PSS) that combine TRM and transition scenarios applied to solve wildlife damage in a suburban city of Tokyo

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Authors	Research area	Level	Research method	Study on
More et al. (2015)	Resource management	Industrial	single case; qualitative	The development of the International Technology Roadmap for Semiconductors (ITRS) that contributes to successful collaboration between firms
Nakamura et al. (2010)	Science and technology forecasting	Industrial	single case; quantitative	Applying citation network analysis to structure the science and technological landscape of aerospace engineering
Oliveira and Rozenfeld (2010)	New product development	Organizational	single case; mixed	The Integrating Technology Roadmapping (ITP) method that combines TRM with project portfolio management implemented at the front Brazilian high-tech company
Pataki et al. (2010)	Strategic planning	Organizational	multiple cases; qualitative	Success factors during the implementation of technology roadmaps in three Hungarian companies
Pearson et al. (2020)	New product development	Organizational	single case; mixed	TRM as a tool to aid agile innovation in a fusion start-up in the UK
Phaal et al. (2004)	Strategic planning	Organizational/Industrial	single case; qualitative	A 'T-plan' fast start TRM method illustrated by an automotive sector-level case in the UK
Silvello et al. (2020)	Strategic planning	Organizational	single case; mixed	A pathway to support technology and innovation plans for startups with a case illustrated a Brazilian company
Son et al. (2017)	Strategic planning	Organizational	single case; conceptual	Applying design structure matrix (DSM) in the TRM process and testing in the case of mobile services
Son et al. (2019)	Scenario planning	Industrial	single case; quantitative	A big data application framework for scenario-based roadmapping using fuzzy cognitive map technique being applied in studying unmanned aerial vehicle

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Authors	Research area	Level	Research method	Study on
Sydow and Müller-Seitz (2020)	Open innovation	Industrial	single case; qualitative	The way open innovation being managed at the inter-organizational network level with the case of International Technology Roadmap for Semiconductors (ITRS)
Tierney et al. (2013)	Innovation management	Industrial	single case; mixed	A Technology Landscaping technique applied to discover new products and innovations in the pharmaceutical industry
Tuominen and Alqvist (2010)	Strategic planning	National	single case; qualitative	A socio-technical roadmapping method applied in Finnish transport system technology services
Vasconcellos et al. (2014)	Project portfolio	Organizational	single case; qualitative	A conceptual model in identifying technological threats and opportunities and a technology roadmap as a tool to improve project portfolio, with a case applied in an automotive company in Brazil
Vinayavekhin and Phaal (2020)	Strategic planning	Organizational	multiple cases; mixed	A Synchronization Assessment Framework (SAF) to leverage enablers of the synchronization process and the roadmapping structure for a company
Vishnevskiy et al. (2015)	Innovation management/ Corporate foresight	Organizational	multiple cases; mixed	Three cases of Russian companies that use an integrated approach of combining Corporate Foresight and integrated roadmaps for corporate innovation management
Walsh (2004)	Strategic planning	Industrial	multiple cases; conceptual	A model for industrial worldwide disruptive technology roadmapping process applied in microtechnology and top-down nanotechnology

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Authors	Research area	Level	Research method	Study on
Wang et al. (2016)	Technology planning	Organizational	single case; mixed	A technology planning framework that integrates TRM, risk management with the real options analysis illustrated with a case of a power module technology project in Taiwan
Yuan et al. (2012)	New product development	Organizational	single case; mixed	An NPD development model that combines TRM with scenario planning and patent analysis, with a case in the planning of digital home products in a Chinese company
Zhang et al. (2010)	Technology forecasting	Industrial	single case; mixed	A TRM process in a case of heavy-duty and large-size CNC machine tool industry in Hubei, China
Zhang et al. (2014)	Science and technology forecasting	Industrial	single case; quantitative	Using semantic TRIZ as a tool to combine term clumping and TRM for studying dye-sensitized solar cells
Zhang et al. (2013)	Science and technology forecasting	Industrial	single case; quantitative	A Triple Helix innovation model that hybrids the semantic TRIZ and TRM analyzed by a case of dye-sensitized solar cells
Zhang et al. (2016a)	Technology forecasting	Industrial	single case; quantitative	A fuzzy set-based semi-automatic TRM generation model to forecast computer science technologies
Zhang et al. (2016b)	Technology forecasting	Industrial	single case; mixed	An analytic method that combines clustering techniques with the workshops in TRM to forecast computer science technologies
Zhang et al. (2016c)	Science and technology forecasting	Industrial	single case; mixed	A hybrid roadmapping technique that includes a term-based TRM composing method, a Problem & Solution pattern-based TRM method, and a fuzzy set-based TRM method applied to the dye-sensitized solar cells

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Authors	Research area	Level	Research method	Study on
Zhou et al. (2013)	Strategic planning	Industrial	single case; qualitative	A P-TRM method that adds the policy dimension into the traditional roadmap applied in the development of wind energy manufacturing in China
Zhou et al. (2011)	Scenario planning	National	single case; qualitative	A systematic approach that integrates TRM with the lifecycle analysis (LCA) and scenario planning applied in a research of the clean coal development in China

Appendix B – Process review on the STRM exercises (from October 2022 to May 2023)

In this document, a process review on the second round of STRM exercises is presented. It explains the details of the exercise that include the activity date/period, objective of each activity (i.e., workshop or exercise), participants, main activities, and deliverables in each step.

Step 1 – "Sharing Day" workshop

Workshop date – 2022. 10. 20

Objective - To clarify the strategy for Tech Lab and to be ready to innovate (i.e., to provide future value proposition ideas in the subsequent strategic planning processes).

Participants – 8 Range Managers (i.e., speakers) and 70 attendees (i.e., listeners)

Main activities – 1) By using the topic roadmaps, Range Managers share the current range strategy as well as the new topics discovered by each range throughout the past year; 2) having a discussion with other attendees.

Deliverables – the current strategy on the strategic landscape roadmap.

Step 2 – Strategic foresight workshop (Part 1 - Trends and drivers)

Workshop date – 2022. 11. 30

Objective - To discuss the new trends and drivers that would impact Tech Lab´s strategy and to be prepared to propose future value proposition ideas (i.e., long-term and visionary ideas) for Tech Lab (Part 2).

Participants - 30 delegates that include all of the range managers, portfolio managers, managers of Tech Business and Development group, corporate venturing group, open innovation group, & some key technical experts.

Main activities – 1) External foresight presentation from Cleantech (i.e., one consulting firm in the energy sector that Tech Lab is working with); 2) Delegates share perspectives (i.e., their top three trend and driver ideas); 4) Delegates work in groups to cluster both internal and external trend and driver ideas into themes; 5) Prioritized trends and drivers. Delegates rank on the importance of the clustered trends and drivers during post-workshop.

Deliverables - Top 11 trends and drivers for Tech Lab.

Figure B.1: Delegates sharing ideas in the workshop[3]

[3] The participants' faces have been blurred based on the General Data Protection Regulation (GDPR).

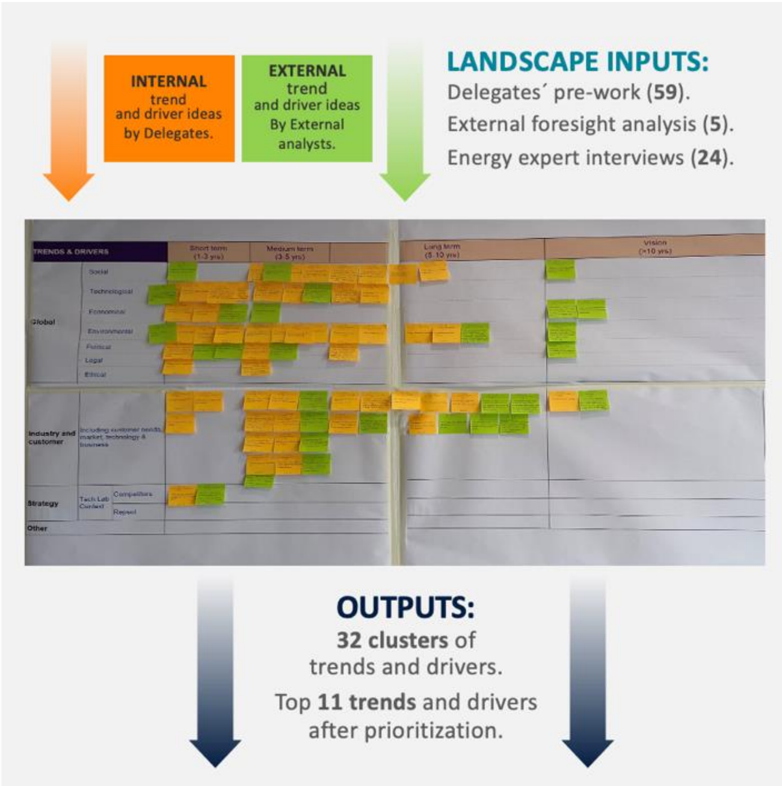

Figure B.2: Landscape inputs and outputs of the Strategic foresight workshop part 1

Step 3 – Strategic foresight workshop (Part 2 – Value propositions)

Workshop date – 2023. 01. 25

Objective - To discuss future value proposition ideas for addressing top 11 trends and drivers derived from Part 1, and to determine a set of key future topics for Tech Lab.

Participants - 25 delegates that include all of the range managers, portfolio managers, managers of Tech Business and Development group, corporate venturing group, open innovation group, & some key technical experts.

Main activities – 1) Delegates share value proposition ideas (i.e., their top three value propositions ideas that could address any of the prioritized trends and drivers); 2) Discussion on pre-clustered topics. In order to save time during the workshop, the core team pre-clustered the delegates' ideas into topics before the workshop and led the discussion on these pre-defined topics with the delegates during the workshop; 3) Assessing and pitching the topics by group. The delegates work in group to assess the topics in terms of breakthrough innovation potential, vision, and future opportunities, and then pitch on each of them; 4) Prioritization of topics. Delegates perform individual assessment on each of the topics and rank on them based on opportunity factors during post-workshop.

Deliverables – 1) A long list of 13 future topics for Tech Lab; 2) A short list of 12 future topics.

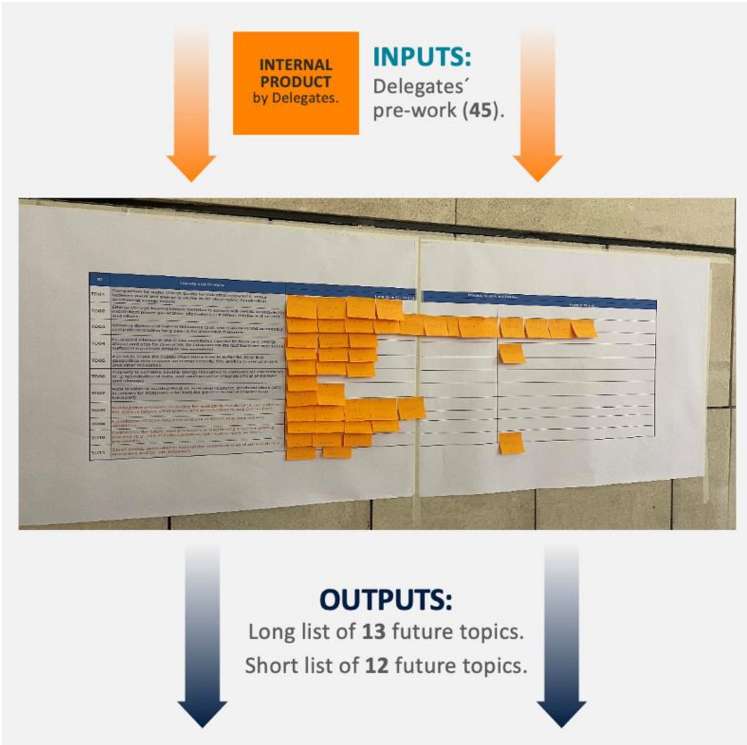

Figure B.3: Landscape inputs and outputs of the Strategic foresight workshop part 2

Step 4 – Topic roadmapping exercise

Exercise period – from 2023. 03 to 2023. 04

Objective – 1) To incorporate the current range strategy into the topic roadmap documents (for current range lines); 2) To analyze the 12 prioritized future topics in detail and roadmap the path for topic development (for future topic lines).

Participants – 35 key technical experts in Tech Lab and 8 range managers

Main activities – 1) Topic roadmapping & preliminary business case development. 2) Technology review on key technologies in each topic in performing exercises on Technology Intelligence and Technology Make vs. Buy; 3) Summarizing all of the analysis and developing mini topic roadmap.

Deliverables – 1) Topic roadmaps, preliminary business cases, technology reviews, mini topic roadmaps for 12 future topics; 2) Topic roadmaps for 6 current ranges.

Step 5 – Synthesis roadmapping workshop

Workshop date – 2023. 05. 11

Objective – To share the outputs of topic roadmapping and develop the Strategic Technology Roadmap for Tech Lab.

Participants – 45 delegates that consist of range managers & key technical experts.

Main activities – 1) Topic roadmap pitch and comments. Each topic group present the topic roadmap and preliminary business case; 2) Plenary review on the drafted integrated roadmap and linkage grids. A drafted integrated roadmap that combines all of the deliverables in the process (including top 11 trends and drivers, roadmaps of 12 future topics, multiple current strategy topics, and linkage grids connecting the "Why", "What" and "How" layers) were prepared before the workshop and reviewed during the workshop among all delegates.

Deliverables – Strategic Technology Roadmap for Tech Lab.

Figure B.4: Topic roadmap pitch during workshop[4]

Figure B.5: Delegates reviewing the linkage grids during workshop[4]

[4] The participants' faces have been blurred based on the General Data Protection Regulation (GDPR).